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VOL. XXXVI

A quarterly paper devoted to the sugar interests of Hawaii, and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

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THE HAWAIIAN PLANTERS' RECORD

VOL. XXXVI

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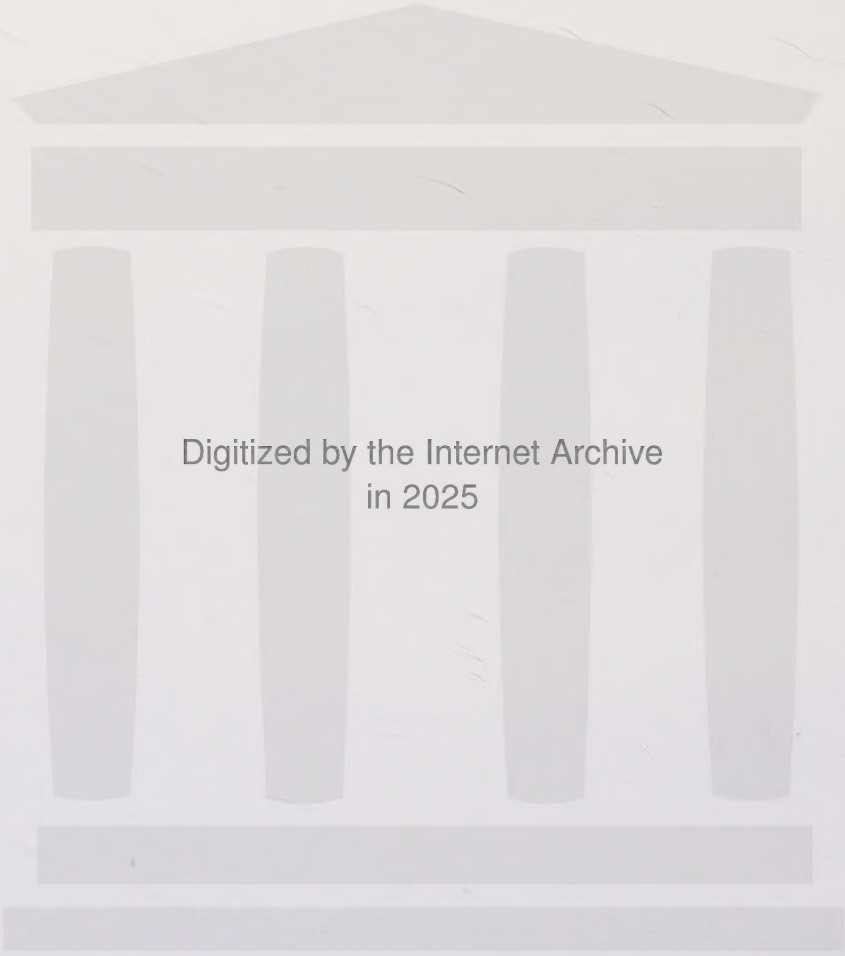

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THE HAWAIIAN PLANTERS' RECORD

Vol. XXXVI FIRST QUARTER, 1932 No. 1

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the Plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Dr. Walter Maxwell:

An article on the life and work of Dr. Walter Maxwell, by Dr. C. A. Browne. Dr. Maxwell was the first director of this Experiment Station. Dr. Browne is the chief of Chemical and Technological Research, Bureau of Chemistry and Soils, U. S. Department of Agriculture, Washington, D. C.

Control of the Nutgrass Armyworm With Arsenical Dusts:

An account is given by *C. E. Pemberton* of the habits and life history of the nutgrass armyworm (*Spodoptera mauritia*), and of the epidemic which occurred on the sugar plantations of Maui in 1931.

Control methods are discussed and details given for the use of arsenical dusts. From large-scale experiments on the Maui plantations, and many tests, the following mixtures are recommended for use:

Finely powdered raw rock phosphate	6 parts
White arsenic	1 part
or	
Finely powdered raw rock phosphate	5 parts
Powdered arsenate of lead	1 part

Plantation Labor:

There is a discussion of plantation labor in relation to labor saving methods and devices.

An Investigation on the Effect of Temperature on Root Absorption of Sugar Cane:

A brief account of previous work dealing with the effect of temperature on root absorption is presented. An experiment on this subject with sugar cane at

the Experiment Station is then reported. It is concluded that in water culture lowering the temperature from 80 degrees to 70 degrees, 59 degrees and 50 degrees Fahr., causes progressively greater decreases in the amount of water absorbed by the roots.

A Further Study of the Influence of Weather on Yield:

Our past studies of the influence of weather on yield were more of a qualitative nature. General conclusions were drawn but no attempt was made to obtain the quantitative relation between weather and crop production. In the present paper the cane yield and juice quality of twenty crops of the Pepeekeo Sugar Company have been mathematically analyzed. It is shown that about 80 per cent of the variation in cane yield from year to year and about 50 per cent of the variation in juice quality are associated with the conditions of temperature and rainfall. This study confirms our previous contention that weather conditions constitute one of the major factors in crop production under Pepeekeo conditions.

Filter Mud and Molasses:

Some notes are given on the use of filter mud and molasses by the plantations.

Distribution of Soil Moisture After Irrigation:

The widespread development of irrigation methods other than the standard Hawaiian contour system in the past two years has aroused increased interest in the economic application of irrigation waters. In the final analysis, the efficiency of an irrigation method must be judged by its ability to distribute soil moisture to the feeding roots of the plant.

In this issue is reported the results of a preliminary investigation on the distribution of soil moisture under the contour method of irrigation at the Waipio substation, the long line or modified orchard system at the plantation of the Waimanalo Sugar Company, and the border method at the Ewa Plantation Company.

Annual Synopsis of Mill Data:

The 1931 Annual Synopsis of Mill Data is included in this issue. The 1931 Synopsis has been published separately as Circular 58.

Dr. Walter Maxwell

By C. A. Browne

Agricultural chemists and experiment station workers whose memories date back to the period of 1890 to 1910 will be grieved to learn of the recent death of Dr. Walter Maxwell at North Conway, N. H., on July 9, 1931, after a short illness from pneumonia. The scientific career of Dr. Maxwell was of such exceptional interest that a brief mention of it should be recorded at the present time.

Dr. Walter Maxwell was born at Marsh House, Greatham, Stockton-on-Tees, Durham County, England, on June 14, 1854. His early life was spent in the country and he intended to devote his career to the management of a country estate but the great depression then existing in the agriculture of Great Britain caused him to modify his original plans. He decided, therefore, to apply himself to agricultural chemical research and after graduating from the Science Department of South Kensington, London, he proceeded to Zurich, Switzerland, where he studied agricultural and physiological chemistry under Prof. E. Schulze. After graduating from Zurich he worked first as an assistant to Professor Schulze, with whom he conducted various investigations upon the chemistry of plant cell membranes and the constituents of leguminous seeds. He then came to the United States where he took a post-graduate course at Harvard University, during the college year of 1888-1889. His research work at Harvard was devoted to investigations upon the carbohydrates, lecithins and other constituents of various leguminous seeds, such as the pea, bean and vetch. In the summer of 1889 he conducted a class in physiological chemistry at the Harvard Summer School.

On September 1, 1889, Dr. Maxwell was appointed assistant chemist in the Bureau of Chemistry of the U. S. Department of Agriculture, where he worked for the next four years under the late Dr. H. W. Wiley upon sugar making experiments. This was the beginning of his connection with an industry that was to demand so great a part of his later attention. He had charge of the federal sugar beet experiment station at Schuyler, Nebraska, and collaborated with Dr. Wiley in the preparation of four bulletins* upon "Experiments with Sugar Beets." Dr. Maxwell's reports upon work at the Schuyler Experiment Station related to the production of native sugar-beet seed, to the cultivation of the beet, to the prevention of losses from deterioration of sugar beets during storage and to other related subjects. These investigations were of a pioneer character, being among the first of the kind to be conducted in the United States. His remarks in 1893 upon the superiority of home-grown sugar-beet seed for native conditions have been confirmed by later investigators and his recommendations upon this subject are still worthy of consideration.

During his connection with the Department of Agriculture Dr. Maxwell conducted various researches upon the organic acids of sorghum juice, the nitrogenous bases in cottonseed, the biological function of the lecithins and other subjects.

* Bulletins 30, 33, 36 and 39, Division of Chemistry, U. S. Department of Agriculture.

Papers upon his scientific work at Zurich, Harvard and the U. S. Department of Agriculture were printed in the American Chemical Journal (1889 to 1893) and in other publications.

Dr. Maxwell resigned as chemist with the U. S. Department of Agriculture on November 13, 1893, in order to accept a research position at the Audubon Park Sugar Experiment Station in New Orleans, La., under the late Dr. W. C. Stubbs. During his period of service in Louisiana Dr. Maxwell published a series of important researches upon the organic non-sugars of cane juice and upon the clarification of cane juice, the results of which are contained in Bull. 38, second series, of the Louisiana Experiment Station. During this period a state of great depression existed in the cotton industry of the South and in response to a prize offer by a New Orleans newspaper for the best essay upon the means of remedying the situation Dr. Maxwell won the award of $500.00.

In 1895 when the Hawaiian Sugar Planters' Experiment Station of Honolulu was organized, Dr. Maxwell, upon the recommendation of Dr. Stubbs, was appointed its first director. During his residence in Hawaii, which was the most prolific period of his scientific career, Dr. Maxwell published numerous reports upon the work of that Hawaiian Station, and wrote various miscellaneous articles upon irrigation in Hawaii, experiments with sugar cane, the lavas and soils of the Hawaiian Islands, and other agricultural and chemical subjects. His series of articles upon the estimation of the elements of plant food, probably available in soils, by extraction with aspartic acid, attracted considerable attention. The credit of inaugurating the first extensive study upon the chemistry of Hawaiian soils is due to Dr. Maxwell.

In 1900 Dr. Maxwell resigned his position in Hawaii in order to accept the directorship of the Bureau of Agricultural Experiment Stations in Australia, where he remained for the next ten years. It was stated at the time of his appointment that the salary (£3,000) was the largest ever offered to any agricultural experiment station director in the world. During the period of his activities in Australia Dr. Maxwell published numerous reports upon the work of its experiment stations, upon cultivation and irrigation, upon the cane sugar industry of Australia, upon feeding stuffs, and various other agricultural topics. In the fifteen years of his directorship of experiment stations in Hawaii and Australia, Dr. Maxwell continued to maintain his former contact with the U. S. Department of Agriculture as special agent for supplying information upon agricultural plants and products.

Upon his resignation from the directorship of the Bureau of the Australia Agricultural Experiment Station in 1910, Dr. Maxwell was appointed a special agent of the U. S. Department of Agriculture for the purpose of studying the sugar cane industry in the Philippine Islands.

During the World War Dr. Maxwell spent much of his time in England, where he rendered distinguished service to the cause of the Allies by his expert advice upon matters pertaining to sugar and other tropical agricultural products and in other ways. It was his misfortune to lose a son at the battle front in 1916 and this bereavement with other family afflictions cast a deep shadow upon the remainder of Dr. Maxwell's life.

After the close of the war Dr. Maxwell returned to the United States, where he selected Washington as a place of residence. He spent his summers at Jackson, N. H., a place to which he was particularly devoted, and it was here, just following his seventy-seventh birthday, that he was stricken with his final illness.

In his later years, although not actively engaged in scientific pursuits, Dr. Maxwell maintained his interest in agricultural chemical research. He was fond of literature and, as a solace for the sorrows which he had suffered, began the writing of verse. In 1925 he published a small edition of "Wayside Verses," printed by Basil Blackwell of Oxford. In 1930 he published "The Master of the Voids," a philosophical poem which was privately printed by the Merrymount Press of Boston. The latter work, of which an excellent review appeared in the magazine section of the Washington Star of January 11, 1931, has attracted much favorable notice.

Dr. Maxwell was a corresponding member of the National Geographic Society of America, a Fellow of the Geological Society of Great Britain and a participant in the work of various scientific and agricultural organizations. He was also a member of the Harvard Club of Boston and the Cosmos Club of Washington.

In the period of his greatest productivity Dr. Maxwell was a most aggressive worker. He was a man of broad vision and the agricultural experiment stations which he established in Hawaii and Australia have developed into institutions of the first rank. His numerous contributions to tropical agriculture, more especially to the agriculture, chemistry and technology of the sugar cane, made him one of the best known workers in this field during the period of a generation ago.

Control of the Nutgrass Armyworm With Arsenical Dusts

By C. E. Pemberton

Extensive outbreaks of the armyworm *Spodoptera mauritia* (Boisd.) have occurred during 1931 in many parts of Hawaii. Portions of each of the main islands suffered. The damage was done both in young cane and in grasslands. Instead of subsiding, as usual, after a few generations, owing to the activity of several different parasites, succeeding broods in destructive numbers have persisted in places since the beginning of the outbreak in April and May to the present date (January, 1932). This armyworm has been most abundant on the island of Maui. Several hundred acres of young cane up to three feet in height have suffered. In portions of many fields most of the leaves were stripped to the bare midrib. In some cases succeeding generations of the armyworm kept the stools bare of foliage long enough to kill the cane. In the majority of the affected territory the cane has recovered; but there has been a distinct setback through cessation of growth for varying periods.

Under the conditions prevailing in Hawaiian cane fields, *Spodoptera mauritia* has been well named the nutgrass armyworm. Nutgrass, *Cyperus rotundus,* is the most persistent and common plant pest of many Hawaiian cane fields. It is especially troublesome on the island of Maui. In spite of almost constant warfare against this by cultural and chemical means, it quickly reappears. Many young fields become carpeted with this sedge. It furnishes an ideal food for newly hatched Spodoptera larvae. Many grasses found in our cane fields are also utilized by the young larvae, but since nutgrass greatly exceeds all other plant pests in most of the Spodoptera-injured territory it may be said to be almost solely responsible for the major outbreaks. In the absence of nutgrass, it is probable that Spodoptera would rarely be noticed, since most, if not all, of the other common grasses which the young worms feed on, can be held in check by the usual weed control methods sufficiently well to prevent large multiplication of this armyworm. This applies especially to the irrigated plantations.

Though some newly hatched Spodoptera larvae do feed on tender young cane leaves and develop to maturity without previously getting a start on grass, the percentage is small and the occurrence of destructive numbers of caterpillars in cane fields practically free of nutgrass or other grasses is not to be expected. Indoor tests with newly hatched Spodoptera larvae strikingly indicate their preference for nutgrass as against succulent cane leaves. When fed cane leaves only, very few young larvae succeed in developing. Where Spodoptera eggs have been laid in quantity in cane fields where nutgrass and other grasses are absent or have been recently removed, the mortality amongst the newly hatched larvae will be very high.

In fields of young cane, Spodoptera eggs are normally laid on the leaves near the tips. Upon hatching, the minute larvae lower themselves to the ground on fine

silken threads. Here they feed on nutgrass or other grasses for about 7 to 10 days, when large numbers of them leave the grass and crawl onto the cane. They are now about three-quarters of an inch or more in length They are conspicuous, easily seen, and their damage to the leaves soon becomes evident. They are usually on the cane from 7 to 10 days. When full-grown they drop to the ground again and pupate just beneath the surface of the soil or beneath trash, stones, lumps of earth, etc. The pupal stage occupies from one to two weeks, when the moths hatch out to start another brood. Their egg-masses can again be seen on the cane leaves.

From the rough summary above it is seen that there are four distinct phases in the life history of this moth, all easily recognized (see chart). First the egg-masses are prominently visible on the cane leaves. Secondly, myriads of young armyworms have appeared on the nutgrass, or other grass if present. Thirdly, quantities of these worms, of good size, are on the cane, and in the final, fourth, phase, they have disappeared underground and have pupated. These four stages are clear cut with very little overlapping of broods in any particular field or sometimes over the whole plantation. This, fortunately, permits effective control by poisoning the insect, particularly in the second phase of its development, when it is confined to the grass and is not yet on the cane.

Arsenical dusts are by far the simplest, cheapest and most effective forms of poison for this armyworm. Dusts can be applied rapidly and efficiently by hand, requiring no machinery, no special procedure in the mixing of the ingredients, and can be transported from the warehouse to any desired spot on a plantation at a moment's notice ready for immediate use. The mixture once made can be held in readiness under cover for an indefinite period.

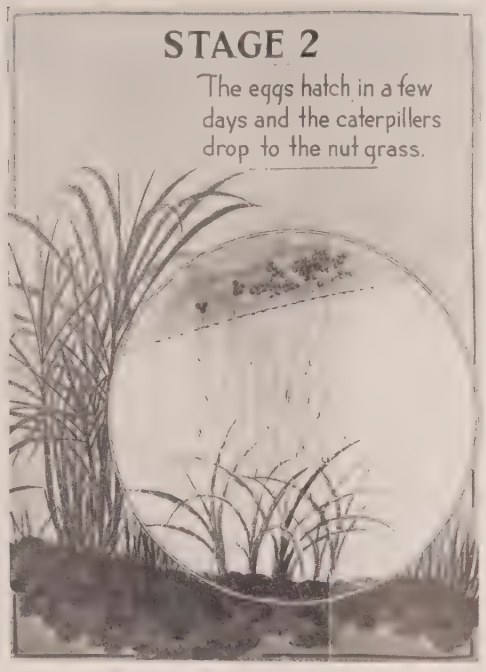
After many tests the following mixtures are recommended and can be depended upon to give complete satisfaction if no rain follows within 24 to 48 hours after application:

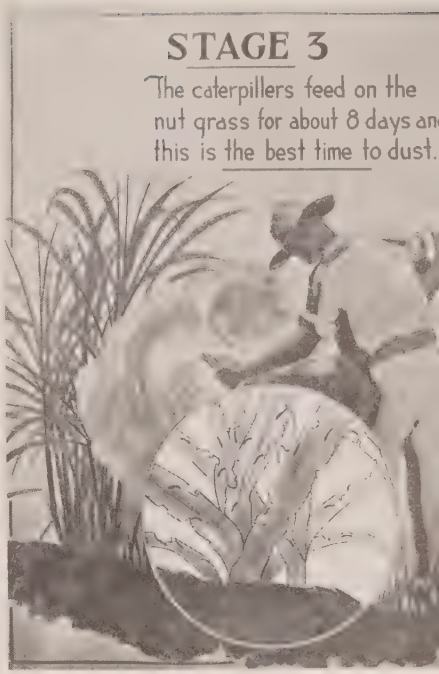
Finely powdered raw rock phosphate	6 parts
White arsenic	1 part
or	
Finely powdered raw rock phosphate	5 parts
Powdered arsenate of lead	1 part

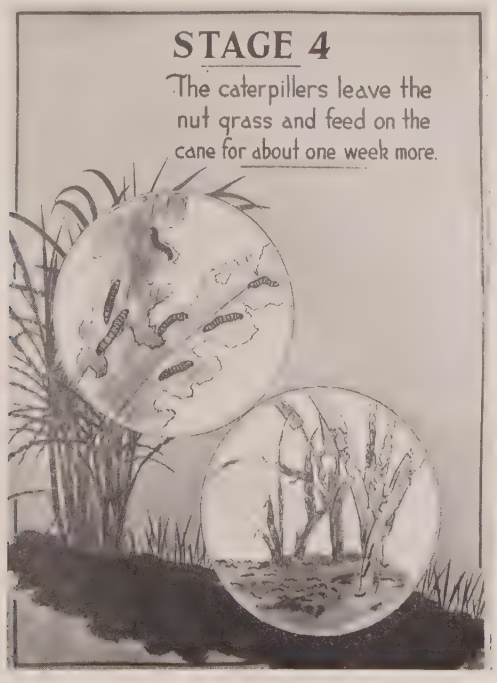
Proportions by weight.

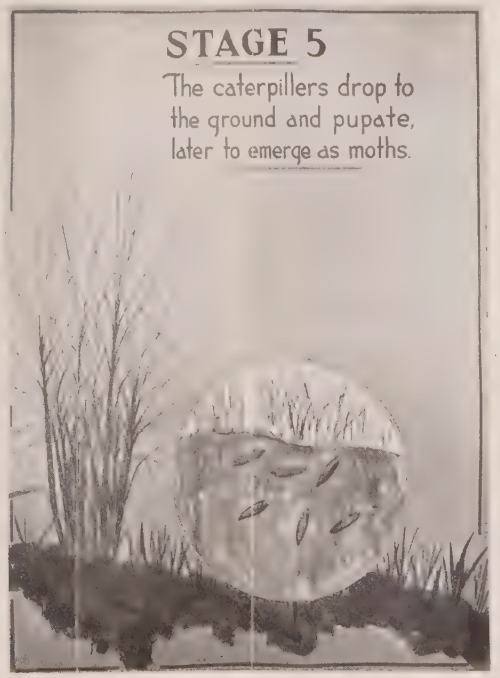
At present prices the commercial white arsenic is obtainable at about one-third the cost of powdered arsenate of lead in Honolulu. Since white arsenic is regularly imported in quantity into the Territory for making the standard sodium arsenite weed killer, it has the additional advantage in being immediately available in any desired amount at all times to all plantations. It is practically insoluble in water and makes an effective dust if combined with an inert substance like powdered raw rock phosphate or finely powdered gypsum.

Raw rock phosphate, when finely ground, is slightly preferable to gypsum as a carrier for the arsenic. Being a commonly used commercial fertilizer, it is always available in quantity. It was first used at Wailuku Sugar Company, with excellent results.









Life history of nutgrass armyworm.

Application of poison dust by sifting from a bag.

Dusting with an American Beauty Duster.

Lime should never be used in combination with white arsenic. It is injurious both to the workers and to the cane. The following memorandum from Dr. F. E. Hance, chemist of this Experiment Station, on the subject is of interest:

> When calcium hydroxide (slaked lime) is added to white arsenic and the mixture becomes moistened or damp reaction sets in which tends to produce soluble arsenite in the vicinity where the dust may settle. If this dust is inhaled by the operator of the outfit, soluble arsenic may be absorbed by the system. If this same dust settles on a cane leaf, when that leaf becomes wet, it probably will suffer just as though it had been sprayed with common arsenic weed spray.

A negligible amount of burning appears on some of the cane leaves when moistened by dew or rain after dusting with white arsenic and raw rock phosphate. It has not been serious and is of no importance considering the benefits derived through the immediate suppression of the feeding armyworms. No burning whatever follows the use of lead arsenate dust in combination with raw rock phosphate or gypsum.

Since powdered arsenate of lead is much lighter than white arsenic and more finely divided, it mixes more uniformly with raw rock phosphate or gypsum and has better adhering qualities also. These advantages are offset, however, by the cheapness of white arsenic and from the fact that in field practice white arsenic accomplished the end sought when mixed with the carrier in such a strong ratio as 1:6, even without the addition of sticking ingredients. Weaker mixtures of white arsenic and raw rock phosphate have been used with success. One part white arsenic to 7, 8 and 10 parts of raw rock phosphate, respectively, have been used with good results; but the 1 to 6 mixture is safer to use owing to variations in the purity of commercial white arsenic and to the difficulty of securing a uniform distribution of the arsenic in the mixture. When the distribution is not entirely uniform the amount of arsenic at times dusted out from a weak mixture would not be sufficient to kill. The 1 to 6 mixture also kills quicker than the weaker preparations and consequently a more certain success follows in case of an early rain after dusting.

The mixing of the ingredients of the above recommended dusts can be satisfactorily done by simply hoeing or raking together the proper weights of each on a solid floor or in a wooden bin. It should be done thoroughly. The workmen should wear dust masks over the mouth and nose while mixing the poison. It has not been found necessary to wear masks in the field when applying the dust. It would be advisable, however, to encourage the use of such masks in the field, especially when men may be applying dust for a week or more continuously. Workers will occasionally develop a mild rash on chafed or scratched areas after dusting for several days. No disturbing results have attended this excepting when lime was first used as a carrier for the arsenic.

For best results the dust should be applied during the second phase of development of the caterpillars. This, as mentioned above, is that period when the larvae are on the grass and are yet too young to have moved onto the cane. With a reasonable amount of observation and experience in the field this period can be easily recognized by field men. A thorough dusting of the grass over the entire

floor of the affected area can be easily accomplished and the young cane entirely saved from damage.

It is useless to apply dust when rain is falling. Should rain fall within 24 hours after dusting it is best to repeat the operation.

If dust is not applied until the caterpillars are upon the cane then both the cane and grass should be dusted.

More than one dusting may be necessary, the succeeding applications occurring about 2 or 3 weeks apart. This becomes necessary when moths fly in from adjacent untreated territory and place their eggs on the cane.

As soon as the cane starts closing in and the grass becomes shaded and less abundant, there is little danger of further armyworm damage within the field. Along grassy watercourses, in fallow fields, and large unshaded irrigation ditches where there is plenty of grass, outbreaks may continue and maturing larvae may crawl from the grass to the large cane and feed; but this damage will only border such open spaces and not penetrate into the field away from the watercourses, ditches, etc. Such places are easily accessible for dusting operations.

Dusts have been applied very satisfactorily in the manner shown in the accompanying illustrations. The poison can be very rapidly spread with a bag. About 25 pounds of the mixture is placed in a sugar bag or flour sack at a time. The bag is held horizontally, as indicated, and rocked by alternately raising and lowering each hand. The mixture, thus agitated, sifts out through the cloth as a fine cloud of dust. The amount of dust let out can be easily regulated by the degree to which the bag is agitated. Usually a sufficient amount of dust is applied by the operator when walking at normal speed if the bag is constantly agitated. This method has shown particular merit in the dusting work at Pioneer Mill Company, Ltd.

The mechanical duster here shown also applies a uniform cloud of dust and is especially useful in directing dust against worms which have crawled well up on cane 3 or 4 feet high. There is very little waste of material when using the mechanical duster. It is somewhat slower in operation than by the bag method, but has given excellent results where used. It is light and easy to operate. Since the dust is discharged from a nozzle held well away from the operator, very little annoyance results from excessive dust about the head or over the body.

The cost for materials and labor should not exceed $3 per acre for one treatment. This will vary depending upon the density of the grass and the age of the cane. When a field is dusted before the worms have left the grass for the cane the cost should be less than the above figure.

Fig. 1. A forester's trail into a Malay jungle.

SCENES IN A MALAY JUNGLE

A jungle is a blanket of vegetation in which all available space is occupied by some form or other of plant life. The Malay States contain some of the finest examples of jungles to be found anywhere in the world. They have great vertical depth because they include many species of trees that attain great heights and they are dense because they include an enormous variety of plants, some adapted to

Fig. 2. Along the edge of the trail.

grow under each and every condition that the jungle affords. There is first a ground cover composed of small ferns and herbs. Above this comes a second story, occupied by the crowns of shrubs, gingers, small palms and tall-growing ferns; in the third story we find the crowns of taller-growing shrubs and palms and then above this may be distinguished story after story until we get to the very top, which is occupied by the crowns of the tallest-growing trees.

Fig. 3. A huge "Meranti" tree in a forest clearing.

In anticipating the structure of such a jungle, one might expect to find huge trees standing close together throughout the jungle, but this is rarely the case, the huge trees usually standing well apart, the intervening spaces being occupied by more slender trees, the crowns of which may reach as high as those of the trees with largest trunks. In such a jungle, the majority of the tallest-growing trees must start up as seedlings from the forest floor and grow up through the successive

Fig. 4. Butt of the "Meranti" tree shown in Fig. 3.

stories until they reach the top. These tallest-growing trees usually push their crowns up rapidly, supporting them on a slender trunk until they reach great height, after which the trunk thickens up, so in a jungle we often find a preponderance of slender trunks, with only an occasional huge trunk.

Vines of many kinds are conspicuous features of the Malay jungle. Like the shrubs and trees, they grow in great variety and sizes. There are some which are

Fig. 5. Twisted stem of a woody vine.

tiny and low growing, while the giants in this class are mighty liana with woody, twisted trunks up to a foot or more in diameter, which climb to the very tops of the tallest trees and then extend their sprawling branches for great distances. Many of the more pleasing vines to be met with are the climbing aroids, plants of the taro family, which have fleshy leaves artistically shaped and cut.

Palms constitute a conspicuous feature in the Malay jungle and appear in a great variety of sizes and shapes. The very common Bertam palm never raises its

Fig. 6. A climbing fig flanked by two aroids.

trunk far above the surface of the ground but produces a dense crown of leaves which are ornamented with an abundance of long, sharp thorns. Then there are the handsome, tall-growing "Nibong" palms, a group of which is shown in Fig. 7. Other palms of frequent occurrence which can give you much trouble are the rattans. These are climbing palms with very slender stems bearing long leaves well supplied with sharp hooks by means of which the plant hangs on to the stems

Fig. 7. A clump of thorny palms, "Nibong."

and branches of the trees as it pulls its crown up through the successive stories of the jungle. The most pleasing palms are the shade-loving ones such as may be seen in Fig. 8. These palms never attain very great height. Their slender trunks are unarmed and make exceptionally fine walking sticks. When dry, they are extremely light but surprisingly strong and durable.

Another class of attractive plants growing in the Malay jungle are the perch-

Fig. 8. A shade-loving palm, "Pinang."

ing plants which live on the trunks or branches of the trees and have no connection of their own with the soil. Among these are many orchids, some with very handsome flowers. Numerous perching ferns and aroids are also to be found but the most remarkable perching plant seen was a bright-flowered ginger which establishes itself high up in a tree, wrapping its fleshy roots into a ball around a branch.

—*Notes by H. L. Lyon. Photographs by C. E. Pemberton.*

Man-Day Performance in Relation to Agricultural Methods and Implements*

By L. D. Larsen

A man with a hoe does a given amount of work. This may be increased materially by special inducements. Piece work, which caters to his pocketbook, is perhaps the commonest means of increasing his labor performance. Competition, which appeals to pride and accomplishment, is also used to bring out more work. Special rewards and honors also accomplish the same thing.

Some interesting developments along this line have taken place in recent years whereby labor performance has been stepped up very materially. Most outstanding examples of this have taken place in the harvesting field, especially with cutting cane. The rate of fertilizing and hoeing has also been increased materially by these means.

This type of development may be considered true man-power development. It embodies elements of psychology and leadership and should prove a most profitable subject for investigation. For the purpose of this paper, however, we shall omit this type of development and confine ourselves to indirect man-power development brought about by the use of better tools, more power, or changed cultural methods.

Not so many years ago plowing in the Islands was done largely with bullocks and with mules. The steam plow replaced animals for this operation to a large extent, and the tractor in turn replaced the steam plow.

Those of us who went to Java two years ago were shocked to find that plowing was still done by man-power and a spade, fertilizer was applied with a spoon, and irrigation water with a bucket.

Only a few years hence we shall look back on the primitive days when planting in the Islands was done by hand, when water was applied in small streams to a 30-foot furrow, while the laborer stood watching it run, when weeds were controlled largely by the hoe, and when fertilizer was carried over the field on a man's shoulder and applied by hand.

The total labor on our plantations is divided, occupationally, about as follows:

Agricultural labor	35 per cent
Harvesting labor	25 per cent
Factory labor	10 per cent
Sundry labor	30 per cent

In our present study we shall consider agricultural labor only, leaving harvesting, factory, and sundry labor for future consideration.

While 35 per cent of the total labor is employed at agricultural field work, this percentage increases during portions of the year to over 50 per cent. The specific operations on which this 35 per cent or 50 per cent is employed may be divided

* Presented at Tenth Annual Meeting of the Association of Hawaiian Sugar Technologists, Honolulu, October 19, 1931.

roughly into (1) preparing and planting, (2) cultivation and weed control, (3) irrigating, and (4) fertilizing.

While a study of these four operations would cover the field of this paper almost completely, there are related factors which influence the situation and which should not be lost sight of. Varieties of cane, for example, have a bearing on labor performance and on labor requirement. Time of harvesting is also a contributing factor.

The following list of subheadings, while dealing mainly with the four operations involved, also touch to a limited extent on certain other contributing factors:

1. Planting machines.
2. Walking vs. riding cultural implements.
3. Mules vs. motor power.
4. Light vs. heavy weeds.
5. Chemical weed control.
6. Irrigation methods.
7. Varieties of cane.
8. Harvesting season.
9. Relation between agricultural labor and total labor.

Planting Machines

Planting machines were first used in the Territory in 1922 and since that time have developed along lines of increasing labor economy. As an average achievement we would estimate an increase of some 300 per cent in man-day performance by the use of planting machines over hand planting.

In a report to the Labor Saving Devices Committee of the H. S. P. A. this year, A. T. Spalding, of Honomu, reports a reduction of from 3.9 man-days per acre for hand planting, to 1.5 man-days per acre for machine planting on his first trial with the machine, and he feels certain that this can be reduced to 1 man-day per acre in the next field, when stops for adjustment and other preliminary work with the machine will be unnecessary. This is under non-irrigated conditions.

George Chalmers, Jr., manager of Waimanalo Sugar Company, in the same report, submits actual field data showing a reduction from 12.95 man-days per acre to 3.6 man-days per acre for planting and first irrigation by the use of the planting machine together with straight-line irrigation.

Ewa Plantation Company reported 20 acres per day with a 4-row machine using 12 men. Honolulu Plantation Company reports 6 acres per day with a small 2-row machine and 6 men.

From the above it would seem quite in order to estimate a 300 per cent increase in labor performance by the use of planting machines. A striking reduction in cost is also shown by these places, but for the purposes of this paper we are omitting cost statistics.

Walking vs. Riding Implements

For inter-row cultural work and weed control mules have long been used in the Islands to increase a man's labor performance. In utilizing mules, however, there

are large discrepancies in labor performance, due to the tools or implements used with the mules, and a study of implements may be more helpful to a plantation than purchasing more mules.

R. M. Allen, manager of Kilauea Sugar Plantation Company, submits a statement showing actual performance for all cultivation work at Kilauea for the past year. This table shows an average of 5.55 acres per man-day for riding cultivators, as against 2.67 as an average for walking cultivators. For the unirrigated area riding cultivators averaged 7.68 acres per man-day.

Mr. Spalding, in submitting a report to the Labor Saving Devices Committee on a new two-row Planet Junior cultivator, reports 6 acres per man-day under non-irrigated conditions.

Mr. Chalmers, with a riding cultivator, under straight-line irrigated conditions, reports an average of 4.10 acres per man-day.

A summary of these reports would indicate an increased performance of at least 100 per cent per man-day by the use of riding cultivators over walking cultivators using mule power. Under less intensive supervision we believe the difference would be greater, since the tendency with walking implements is to stop for a rest at the end of the row and in out-of-the-way spots, while a man riding on an implement is willing to keep going.

The writer once watched a riding cultivator working alongside two walking cultivators in some rather tall cane and fairly short lines, and without an overseer. On several counts that were made unbeknown to the drivers, the riding cultivator with two horses and one man would go four times up and down the lines while the walking implements went once.

The chief reason for the almost universal use of walking implements in these Islands, the writer believes, is mental inertia. A riding implement must be adjusted and watched and can only be used to advantage at an early stage of the weed growth. A walking cultivator can be used at any time and under most any conditions.

The writer has found it extremely difficult to accustom plantation overseers to the use of riding mule-drawn implements. The stable boss, the field overseer, and the section luna are alike in this respect. With the slightest let-up of pressure or specific instruction, they revert immediately to walking implements. They have always used them and know they will do the job with a minimum of mental effort. They have been trained to think in terms of a job to be done and not in terms of man-day performance or expense.

Mules vs. Motor Power

As in the case of mules, the performance with tractor power seems to depend largely on the implement used. According to Mr. Allen's figures, a small tractor with men walking behind holding individual walking cultivators seems to be no more economical of man power than a walking mule-drawn cultivator. It would appear, therefore, that mule power may be fully as economical as tractor power *per se*. The chief factor in favor of tractor power in the field seems to be the fact

that it is more adaptable for handling larger implements and that it is possible by this means for each man to utilize more units of power.

The following statistics, submitted by Mr. Allen, give a summary of all cultivation work on that plantation for the past year. They show performance and cost for different types of implements used, comparing walking, mule-drawn riding, and tractor-drawn implements.

Implement	Acres per Unit	Acres per Man Day	Cost per Acre
Fordson pulling 3-9 tooth cultivators, 4 men in unit, 3 of them holding cultivator	8.60	2.15	1.44
Two-row riding cultivator, 1 man, 2 mules	5.55	5.55	0.68
Walking cultivator, 1 man, 1 mule	2.67	2.67	1.34
Riding disk cultivator, 1 man, 4 mules	4.26	4.26	0.87
Rotary hoe, Fordson and 1 man	4.04	4.04	1.72
Canoe plow, 1 man and 1 mule	3.37	3.37	0.80
Subsoiling ratoons, one 2-ton tractor, and 3 men	8.38	2.80	1.50
Farnall with 3-row cultivator, (1 field only)	20.00	20.00	.25

There is considerable difference in the performance of any implement in irrigated and unirrigated lands, due mainly to the time consumed in crossing the level ditches in the irrigated lands.

The following table shows the average performance of our various implements under unirrigated conditions only:

Riding cultivator, 1 man, 2 mules	7.68	7.68	0.46
Riding disk cultivator, 1 man, 2 mules	6.00	6.00	0.59

In computing the above costs, the following values were assumed:

20 HP Caterpillar day	$ 6.00	
Fordson day	5.00	
Man-day	1.75	
Mule-day	.90	$13.65

Cultivating with a two-row high clearance 10 caterpillar, Mr. Chalmers reports 12.8 acres per man-day. With a 30 Best two-row cultivator, J. M .Ross, of Hakalau, reports 16 acres per man-day. John T. Moir, Jr., of Koloa, cultivating with a 3-row Massey-Harris 4-wheel-drive tractor reports 20 acres per man-day under favorable conditions.

A study of these figures would indicate that a riding cultivator performs about twice as much work per man-day as a walking cultivator; a small direct-attached 2-row tractor cultivator will do twice as much as a riding cultivator; a 3-row direct-attached tractor cultivator will do half as much again. Thus in the evolution between a walking cultivator and certain types of tractor cultivators now in use, a man's labor performance may be increased from 2½ to 20 acres per day, or 800 per cent.

There are cases where riding cultivators are not feasible, and others where tractor implements are not desirable. Our aim therefore should not be to eliminate the mule or the walking type of implements but to utilize the faster and cheaper types of implements whenever possible. It is often claimed that tractor imple-

ments are not feasible under wet weather conditions, and we have seen cases where this type of implement has been abandoned for this cause alone. In other cases, however, it has been found that so much more area can be covered during suitable weather by the use of tractor implements that cultivation during wet weather becomes unnecessary. From an agricultural point of view it is also probable that when soil conditions are too wet for working tractors, any or all implements would be kept out of the field to advantage.

Another factor bearing on the use of power-drawn implements is the labor personnel. With the island-born laborer, who is becoming of increasing importance on our plantations, handling a tractor-drawn implement seems to be a much more desirable occupation than walking behind a mule. It seems rather important that we begin catering more to this type of labor and there is perhaps no field more promising in this respect than mechanizing the agricultural work.

Cultivation in Light vs. Heavy Weeds

One of the chief requisites for economical weed control by riding and tractor-drawn implements is to get the weeds young. It is usual in these Islands, where we are accustomed to the walking mule-drawn cultivator, to wait for the weeds to attain a husky size before attempting to eliminate them. One feels then that something is being accomplished by the effort and it is customary to go back and forth over the lines as many times as may seem necessary. Mr. Allen, in his report to the Labor Saving Devices Committee, submits some interesting data pertaining to this point:

> Too much stress cannot be laid on the economy of cultivating while the grass is small. If the field is allowed to go until the grass is big it is necessary to run 3, 4 or even 6 times a line and the costs consequently increase tremendously. The following data illustrate this point:

Implement	Acres per Man-day	Cost per Acre	Remarks
Walking cultivator, 1 man, 1 mule	2.39	1.11	Light grass; once a line.
Walking cultivator, 1 man, 1 mule	0.99	2.68	Heavy grass; 2-3 times per line.
Walking cultivator, 1 man, 1 mule	0.54	4.97	Very heavy grass; 5-6 times per line.

> It can readily be seen that frequent light cultivations should be practiced.

The Horner harrow, which is the leading cultivation equipment used on the wet, unirrigated plantations, was designed on a presumption of heavy weed growth and more especially honohono. It gathers the weeds into piles where a majority of them are covered and choked out. This type of cultivation results in numerous piles of dirt and weeds at short intervals in the field. These piles interfere seriously with riding and tractor implements and must be eliminated before efficient work of this kind can be attempted. Whether or not this type of cultivation can be eliminated and the honohono kept young enough for riding implements

remains to be seen. An interesting observation along this line comes from Mr. Ross in writing about a 2-row cultivator built on a 30 Best tractor at Hakalau:

> The possibilities of this cultivator are such that we look forward to dispensing with all Horner cultivators and it is possible that with the present clearance of the tractor we can get all our fields so well cleaned up with this cultivator that we can have all our cultivation finished before the cane gets so high as to prevent the 30 working in it longer.

If Mr. Ross's hopes materialize it will be a big step toward eliminating the heavy weed system of culture that has been common in the unirrigated districts.

Chemical Weed Control

Since a special paper on this subject will be presented at this meeting we shall not go into details. Suffice it to say that statistics obtained by the writer would indicate an increased labor performance of several hundred per cent by the use of poison sprays. From the point of total expense there are cases where the superiority of poisoning over hoeing is questioned. From the point of labor economy, however, the question is hardly debatable.

Mr. Allen submits figures on a very grassy field which required a total of 1.90 man-days per acre to spray at a total cost of $4.35 per acre. He estimates that to hoe this field would have required 7 or 8 men per acre.

In light grass where hoeing is easier the difference in favor of spraying becomes less and there is a point where the economy of spraying becomes debatable. Where implements can be handled to advantage the economy of spraying from a labor performance point of view is also questionable. However, with spraying as with implement work the labor performance varies with the implement used. Most statistics available at present refer to knapsack spraying. Olaa with its sled spraying shows a somewhat better performance. Mr. Maze, of the Labor Saving Devices Committee, recently developed a mule-drawn sprayer which shows promise of increasing the labor performance several hundred per cent over the knapsack. A pack-saddle sprayer has also been developed which may add materially to man-day performance in spraying.

Irrigation Methods

The greatest development along the lines of increased labor performance in recent years has been brought about by changes in methods of irrigation and the accompanying changes in field layout.

The standard performance in the Islands with contour irrigation has been approximately 1 acre per man-day. The modified orchard system which has been in use at Kilauea for some 10 years increased this for Kilauea to an average of nearly 7 acres per man-day. Under favorable conditions this has been brought up to 15 acres or more per man-day. By the border system Ewa Plantation Company has attained an average performance of 8.4 acres per man-day and a maximum of 37 acres. At Wailuku their controlled cut-line system gives an average of 6 to 9 acres per man-day, and under favorable conditions will run 12 acres per day. The Koloa system averages around 2½ acres per day, and runs up to

4 or even 5 acres under favorable conditions. The increase shown by these systems varies between 250 and 1000 per cent or more.

Closely connected and essentially a part of these new irrigation systems is the field layout, which in turn has a bearing on other field operations.

The border system devised at Ewa and the modified orchard system of Kilauea both involve parallel line planting, which in turn expedites other field operations from planting to harvesting. At Kilauea this factor is far more responsible for the labor performance than is irrigation. While irrigation alone has been reduced to less than 3 man-days per acre per crop (on irrigated fields) the total number of men affected by this is far less than the total reduction involved through planting, cultivating, fertilizing, etc. Thus, although we refer to these new systems as irrigation systems, they involve changes resulting in increased labor performance in practically every cultural operation.

Varieties

Varieties of cane have a direct bearing on labor performance and labor requirements. In the harvesting field this is recognized to the extent that different cutting rates are paid for different varieties.

In the cultural work necessary in bringing cane to maturity the variety is an essential factor and with the possibility of future labor shortage, this subject should be given more consideration than has been the case in the past. The Uba or wild blooded types are undoubtedly the easiest of all our varieties when it comes to agricultural labor. Conditions may arise when a considerable amount of yield can profitably be sacrificed for the sake of labor economy. It is not certain, however, that a sacrifice of yield will be necessary in the use of these quicker growing cane types. The eminently successful Java canes contain this blood and it seems most probable that in the many new seedlings of this type that are at present being propagated in the Islands some will be found that can close in with a minimum of labor requirement without sacrificing yield.

Harvesting Season

Perhaps the principal drawback to increased labor performance in the Islands is the prevalent oversupply of labor in the off-season. Where a long off-season occurs we all know the difficulty experienced in keeping the labor busy. Work must be saved for the off-season. Under this condition interest in increased labor performance tends to lag. Reducing field labor by 300 per cent and putting the same amount into unnecessary off-season work has little practical appeal, and before any marked progress can be made the off-season oversupply must be eliminated. If we are to continue supplying employment the year around there are but two ways of solving this problem. The first is harvesting machinery; the second is to lengthen the harvesting season.

The first method looks rather promising at present for certain types of plantations at least. Rapid strides are being made with harvesting machinery on the mainland and in Australia and it is hoped that something along this line may be undertaken in the Islands before long.

The second method of approach, that is, extending the harvesting season through intermittent harvesting or slower harvesting has had considerable study in the Islands and has had several practical and successful demonstrations. A graph shown on page 16 of Mr. Chalmer's paper entitled "Short Cropping with Relation to Yields," presented at the annual meeting of the H. S. P. A. in 1930, brings out the possibilities of this method most forcibly. While the graph is taken from a hypothetical case that would not necessarily conform to actual experience, it shows a reduction of 35 per cent in man-days required on a plantation by eliminating the peak requirements due to continuous and forced harvesting. This is not a popular subject in the Islands as it upsets the standard Hawaiian cropping practice and beliefs; furthermore it does not offer the same possibilities in all cases. It should be borne in mind, however, at least as a possible resort in case of stringent labor shortage.

In this paper we are not dealing with the economic aspects of such a procedure other than its relation to labor and total labor performance. We believe, however, that the economic phase of this situation should receive careful and unbiased study. In spite of all the quality ratio curves showing reduced sugar returns after June and July, the writer is of the opinion that other factors than time of year have a marked if not a predominating influence in forming these curves. We feel, however, that the subject is too intricate for detailed consideration at this time. We bring it up with the hope that more study and thought may be given the matter in the future.

Relation Between Agricultural Labor and Total Labor

If man-day performance for planting, cultivating, irrigating, and other field operations can be increased by several hundred per cent the effect on total labor should be quite appreciable and should make a distinct impression on total pay roll.

Agricultural field labor averages about 35 per cent of total labor. If this is cut in two, it should affect total labor directly by about 17½ per cent. If it is cut in three it will affect total labor directly by 23 per cent. However, indirectly, it also affects other sundry labor, so that the total reduction would be somewhat more than the 17½ or 23 per cent indicated. It would also reduce material cost, for housing, medical expense, H. S. P. A. labor costs, etc., to an appreciable extent.

In order to check on the actual effect of the faster methods on total man-days and pay roll, we have made a study of this on some plantations that have adopted these methods to a greater or lesser extent. From this it would appear that the figures reported above are not far fetched or beyond practical accomplishment at the present time.

Ewa Plantation Company adopted border irrigation and layout some two years ago and today has 1,500 acres under this system. Since adopting this method on a commercial scale some two years ago the total men on their pay roll has been reduced by some 300-odd men, of which Mr. Renton considers 98 are due directly to the border irrigation.

Wailuku Sugar Company early this year adopted the Wailuku controlled cut-line system on an extended scale for their ratoons and went into straight-line layout for their plant cane. Although the changed method applied to but one-third

of their 1932 crop and to practically all their 1933 cane, and had been in operation but a few months, the effect on labor in the field and on total pay roll soon became evident. The following table gives a comparison of the man-days used in cultivation contracts for the months of April, May, June and July in 1929, 1930 and 1931. It indicates a reduction of 36 per cent in cultivation contractors over 1930 with practically the same area under contract:

CULTIVATION CONTRACTS

DAYS

	1929	1930	1931
April	5,074	5,254	3,523
May	6,557	6,750	4,454
June	5,982	6,664	4,120
July	5,649	6,688	3,946
Total	23,262	25,356	16,043

A comparison of pay roll and men on pay roll also indicates a similar reduction.

Kilauea Sugar Plantation Company has used straight-line irrigation and straight-line culture since 1922. It is the most outstanding example of increased labor performance that we have on record. In 1922, straight-line irrigation was started in the plant fields and controlled cut-line irrigation was started in the ratoons. Since then the entire place has been put under straight-line culture, machines have been used for planting whenever feasible and riding implements or tractors have replaced walking implements and hoes whenever possible.

Previous to the straight-line layout around 40 man-days per acre were required to bring cane to maturity. By 1929, this had been reduced to an average of 15 for the entire crop including planting. This indicates an improvement of nearly 300 per cent in labor performance for field work. The following table covering five-year periods is presented to show the correlation between this decrease in field labor and total labor:

KILAUEA SUGAR PLANTATION COMPANY

LABOR DATA

	1919	1924	1929
Unskilled adult males (average)	627	364	435
Planters (full time)	90	None	None
Total adult male	717	364	435
Tons cane harvested	49,362	48,310	91,899

These figures show a reduction in total labor of 50 per cent between 1919 and 1924, with approximately the same cane tonnage harvested. Between 1919 and 1929, with the cane tonnage doubled, the labor is still reduced by 40 per cent.

If we assume .6 man-day for harvesting and manufacturing (which is a fair average for Kilauea) the additional cane in 1929 over 1919 would require 25,522

additional man-days for harvesting and manufacturing or 92 additional men on pay roll working an average of 275 days per year. Deducting this from the 1929 total brings this to 343, a reduction of 52 per cent or an increased labor performance of more than 100 per cent for the whole enterprise. In this case an improvement of 300 per cent in agricultural labor performance was accompanied by a 100 per cent increase in total labor performance.

A Preliminary Investigation on the Effect of Temperature on Root Absorption of the Sugar Cane

By H. F. Duncan and D. A. Cooke

The rate of water absorbed by the roots of sugar cane on different soils and under various climatic conditions has long been a subject of debate. Is it only a matter of the per cent of moisture, or do climatic factors, such as the temperature of the soil, also have an effect? This experiment was planned with the purpose of at least finding out whether the root absorption of a sugar cane plant growing in water would be affected by the temperature of that water.

Historical

As long ago as 1860, Sachs(1), the German physiologist, first began to study the slowing down of root absorption due to lowered temperature. He noticed that many plants with large, succulent leaves, such as the tobacco and the pumpkin, wilted when cold weather set in. He decided that this was due to lessened water supply from the roots and tried an experiment to test the theory. He placed a potted tobacco plant in a warm room and after watering the soil thoroughly he surrounded the pot with ice. The plant soon began to wilt. On removing the ice and heating the soil the plant recovered without additional water.

Other investigators, the Frenchman, Vesque(2) in 1878, and the Bulgarian, Kozarov(3) in 1897 worked more accurately with potometers. This apparatus is also used in the present experiment and is described more in detail later. Both Vesque and Kozarov found slower rates of absorption at lower temperatures.

With regard to the present status of the question two modern authorities may be quoted. The American ecologist, J. E. Weaver(4), in a book published in 1926 says "The rate of root absorption, as with all the physical and chemical processes taking place within the roots, is decreased by a lowering of the soil temperature. A low temperature permits only a slow rate of water absorption."

Maximov(5) the Russian physiologist is the other writer. He states (1929) that "One of the environmental factors which most strongly influences the water supply of the plant is undoubtedly the temperature of the soil. As the general regulator of chemical reactions as well as of vital functions, temperature must naturally exert an influence on the rate of penetration of water into the cell, and consequently on the rate of absorption of water by the root." He adds, however, that all plants are not equally affected by the temperature of the soil. Certain hardy winter cereals continue to give off water when the pots in which they are growing are placed in snow. Tropical plants, on the other hand, are much more sensitive.

As far as root absorption in sugar cane is concerned, nothing can be found in the literature on this subject. J. P. Martin in an unpublished test observed previously watered sugar cane seedlings to wilt when the soil temperature was reduced to about 8° C. (46.4° F.). It is possible that other work has been done, but so far no account of it has appeared.

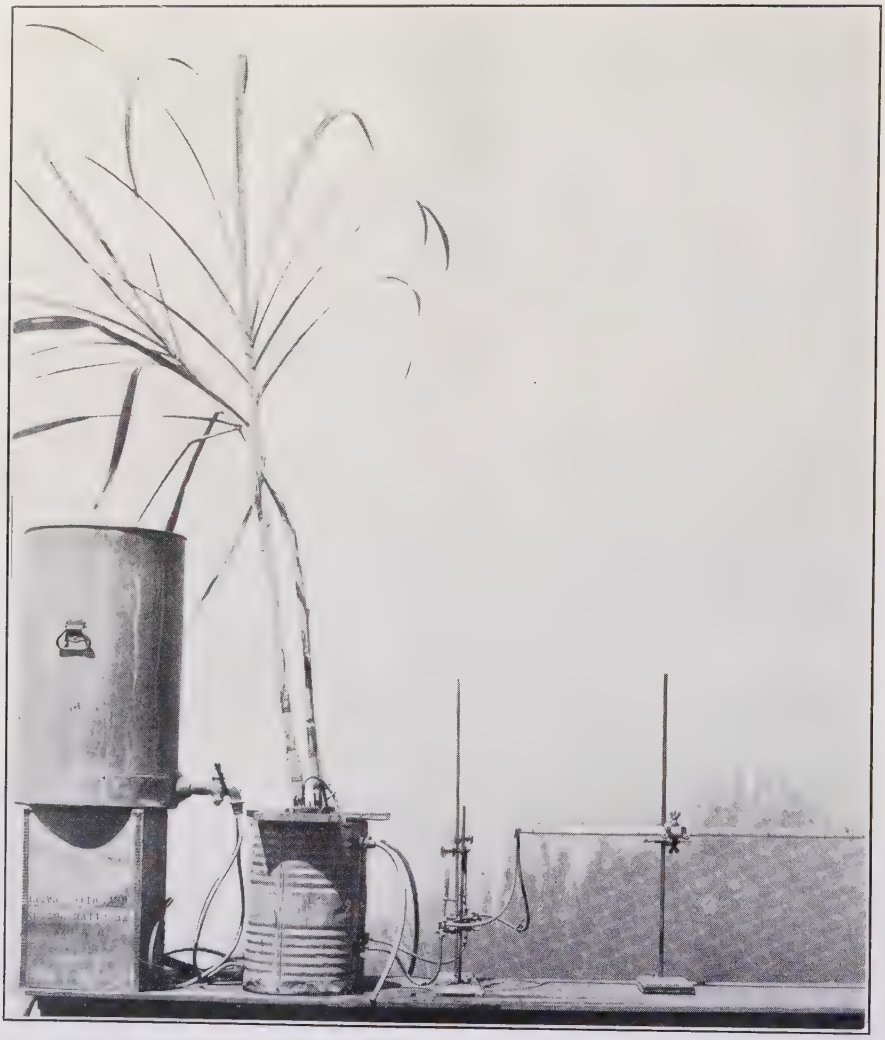


Fig. 1
The apparatus set up for an experiment.

Apparatus and Experimental Technique

The apparatus used in these experiments is known as a closed potometer (Fig. 1). This consists of a plant with its roots in an air-tight vessel containing water. As the roots absorb water, the amount is measured in some convenient manner. In these experiments the method of having a horizontal glass tube placed against a centimeter scale is employed. Water used by the plant is replaced by water from the tube and the relative amount for any given time can be read off in centimeters on the scale.

The plants to be used were selected in the field and layered, according to the method of Dr. H. L. Lyon and H. Brodie(6). This method is a modification of

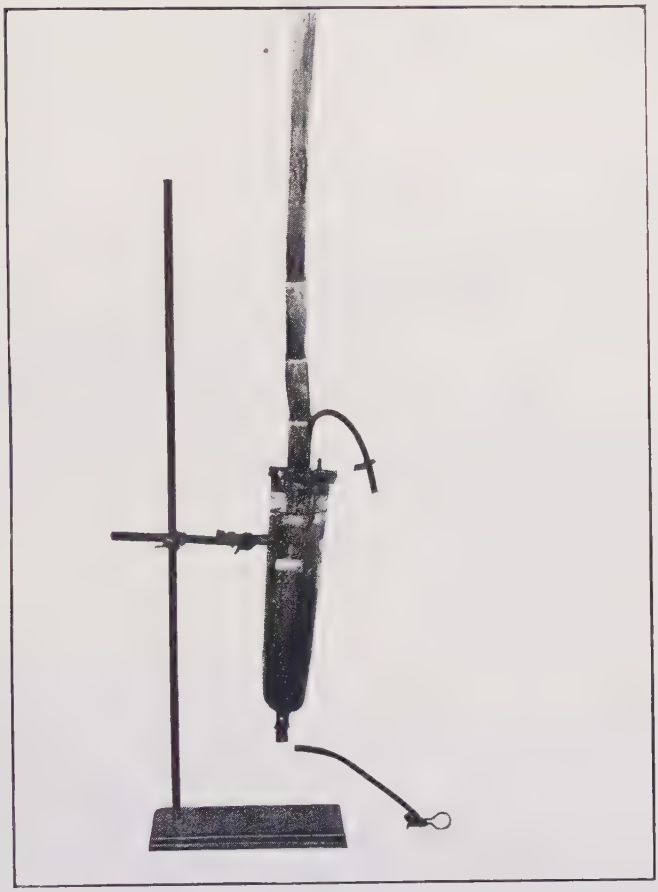


Fig. 2

A cane plant sealed in the soil percolating jar. The rubber tube at the top is used to run off the water when no experiment is in progress. The tubing at the bottom leads to the scale.

that used by Venkatraman and Thomas in India(7). H 109 was the cane variety used. Stalks of from 6 to 8 internodes were selected. After roots had developed, the stalks were cut and sealed in soil percolating jars. These jars were used as plant containers throughout this work. They were all of approximately 1500 cc. capacity and proved most satisfactory (Fig. 2).

The seal, in addition to being air-tight, had to be strong enough to support the plant. After various methods were tried, the following was adopted as the most efficient. A large cork, one-half inch thick, was cut down to a little larger than the circumference of the percolating jar. It was then halved, and hollows made in the center of each half, so that the cork fitted snugly around the cane stalk. Two other holes were bored, one for a six-inch piece of glass tubing, the other for a thermometer. The glass tube protruded one-half inch below the cork. The thermometer was inserted well down into the jar, and as near the center as the

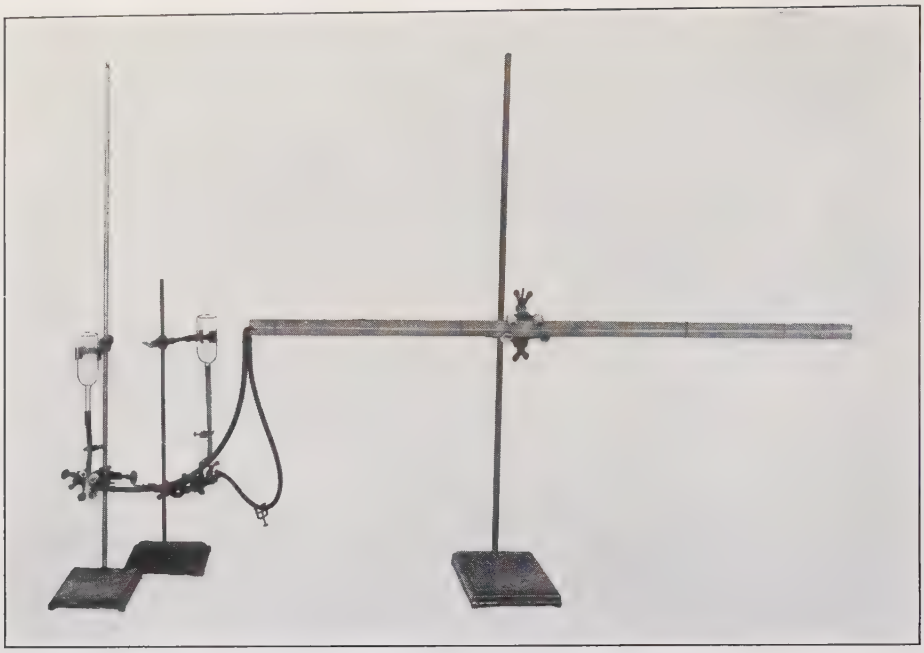


Fig. 3
The scale with the connections to the plants removed.
The funnels for filling the scale tubes to the starting point are shown at the left.

cane stalk would permit. The cork after being placed around the cane stalk, was forced into the jar, so that its top was one-half to three-fourths of an inch below the top of the jar. Any imperfections in cutting the cork were plugged with gum and the whole surface then thickly shellaced. When dry, a one-half to one-fourth inch layer of a mixture of glycerine and litharge was laid over the cork. This was allowed to dry, and then shellaced several times.

The plant container was suspended in a water bath. The bath consisted of a calcium carbide can into which three holes were reamed. One hole was cut at the bottom for a water inlet, another at the top for an overflow, and a third on a level with the base of the plant container to allow for the passage of the rubber tubing from the percolating jar to the measuring scale.

The scale, as stated before, consisted of a horizontal capillary tube fastened to a meter stick (Fig. 3). The capillary tube was connected directly to the base of the plant container by a rubber tube, which made possible with careful handling an unbroken water column from roots to scale. A funnel was set in between the plant and scale by means of an inverted T tube. This funnel was placed high enough so that when it was full of water and the tube open, the meniscus in the scale was sent 3 or 4 centimeters past the usual starting point of the readings. On opening a screw clamp between the funnel and the main column, it was then possible to reset the meniscus when a reading was to be made.

The process of making readings was quite simple. The water levels were checked in container, funnel and scale. The aeration tube in the seal was closed

and the meniscus allowed to run as far past the starting point as the slope of the tube would allow. This never exceeded 5 cm. if the apparatus was set up correctly. The funnel clamp was then closed and as the meniscus passed the starting point on the scale, the time was taken down. After the specified time for the reading was up, the position of the meniscus was again noted, together with container and room temperatures. Any immediate environmental change such as rain, dim light, etc., was also recorded at that time. The difference between the two points gave the relative rate of root absorption in centimeters by the scale for that length of run.

Several difficulties were encountered as the experiment progressed. One was the necessity of keeping the plants in a healthy condition in spite of the air-tight seal. In the hot greenhouse, unless some aeration was provided, the water in the jars soon became foul.

This condition was finally corrected by arranging a small piece of glass tubing in the cork so that it projected about one-half inch below the bottom of the seal. A very thin air cushion was therefore formed at the top. This protected the seal and still allowed water to overflow through the tube when it was run in under a slight pressure at the bottom. When observations were not being made, a slow stream of water was in this way kept circulating through the container. When an experiment was in progress this tube was of course sealed.

First attempts at lowering the temperature of the water in the plant container were made by adding ice to the outer bath alone. This caused the plant container and tube to function as a gigantic thermometer. In cooling, the water in the container contracted, causing an abnormally large absorption reading to be made. That this increase was due to water contraction was proven by experiments in which the jar without any plant was sealed and filled with water. At constant temperature there was no flow in the scale tube. A drop in temperature, however, resulted in a flow that increased the greater the drop in temperature. An attempt was made to rectify this error by determining a coefficient of contraction per degree to be subtracted from each reading. This, however, was found to be unsatisfactory and discarded.

In the method finally adopted the water was cooled a little below the desired temperature in a large tank with an outlet in the bottom. When the temperature of the water became constant, the bath and plant containers were drained of their water for a second or so and immediately refilled from this tank. Water was then allowed to run through the container for several minutes to give both stalk and roots a chance to reach constant temperature before readings were made. The capacity of the tank was sufficiently large so that water of the same temperature could also be circulated in the outer bath during readings.

This method worked very well for the most part. The only defect was that it was difficult to determine beforehand the temperature which would result within the plant container after the cold water was added. After a number of trials, however, this could be estimated within several degrees.

The length of time for each reading made quite a difference to the results when graphed. It was found that the shorter the period of the run the more fluctuations in the curve. This was probably because small errors in the observations had an

exaggerated effect. Longer readings gave a more regular curve. On the other hand, too long a period would tend to make the apparatus not sensitive enough. In general, 5-minute runs seemed to be a good compromise.

It soon became evident that through its effect on leaf transpiration, light was one of the most important factors in root absorption. On a cloudy day root absorption fluctuated very greatly, rising during a sunny spell and falling when clouds intervened. When experiments were run at night under constant electric light, most of these irregularities were eliminated. This resulted in a more uniform curve but with much less absorption due to the lessened transpiration.

As the plants developed the rate of absorption increased to the point where over 100 centimeters of water, the length of the scale, were absorbed in 5 minutes. Glass tubes of different sizes were tried and one of one-eighth inch inside diameter used in place of the capillary tube. This slowed down the rate of flow so that 5-minute readings could again be made.

When two plants were growing under the same environmental conditions, it was found that their water consumption curves ran in a more or less fixed proportion to each other. See Charts I, II and III. A factor could therefore be obtained by dividing the root absorption of the check plant by the root absorption of the plant which was to have its root temperature lowered. Multiplying this factor each time by the absorption of the check, it was possible to determine theoretically the amount of water the other plant would have used if the temperature had not been lowered. This theoretical curve is shown by a dotted line in the graphs. This comparison made it important that for each reading of the treated plant, there must be a corresponding reading of the check at approximately the same time. Observations therefore were started within one minute of each other at the very most.

Results

In order to make interpretation of results easier, a graph was made of each run. The root absorption of both plants as well as the temperature of the air and plant container were plotted on the same sheet. The relative absorption is shown by heavy lines, while the temperature of the room and plant containers is designated by light lines.

Charts I and II show the extreme differences between absorption with sunlight during the day and at night under electric light. Notice the effect of the variations in light in Chart I, also the great difference in the total rate of absorption between night and day.

Chart III, a run made about two months later, shows the two plants still running in the same relationship to each other. Note the steady rise up to noon as the sun grows brighter.

In Chart IV the temperature was lowered from 27.5° C. (81.5° F.) to 21.5° C. (70.7° F.). Despite a falling off in root absorption in the check, there appears to be some lessening in the absorption rate due to this lowered temperature.

In Chart V the temperature was reduced to about 15° C. (59° F.). Slowing down of root absorption is quite evident. At the end of the run the plant had still not regained its normal rate of water consumption.

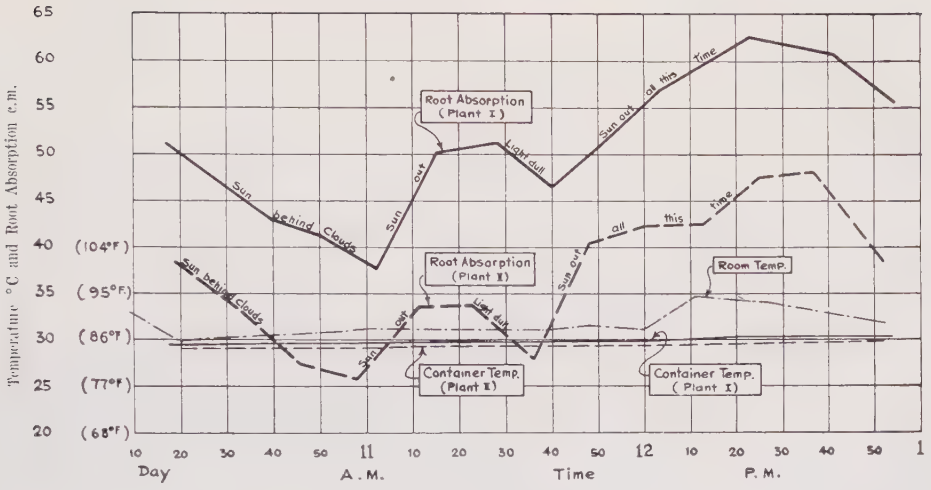


Chart I

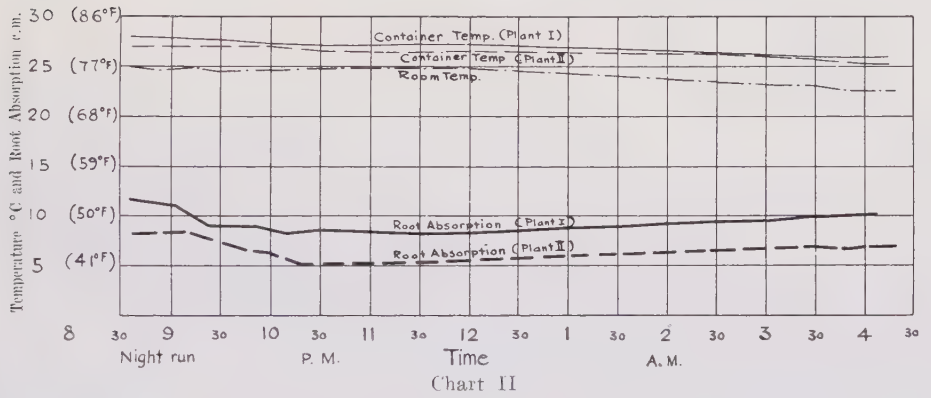


Chart II

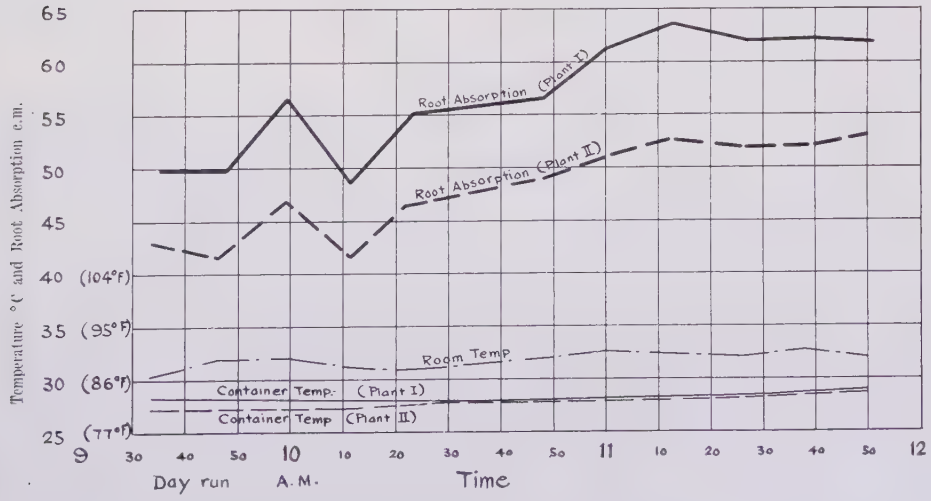


Chart III

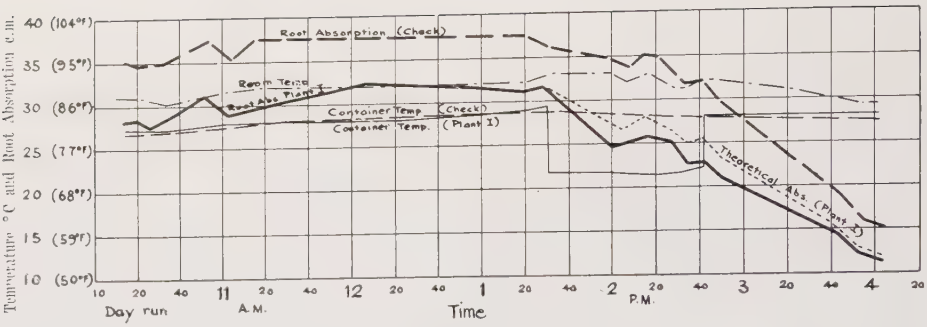


Chart IV

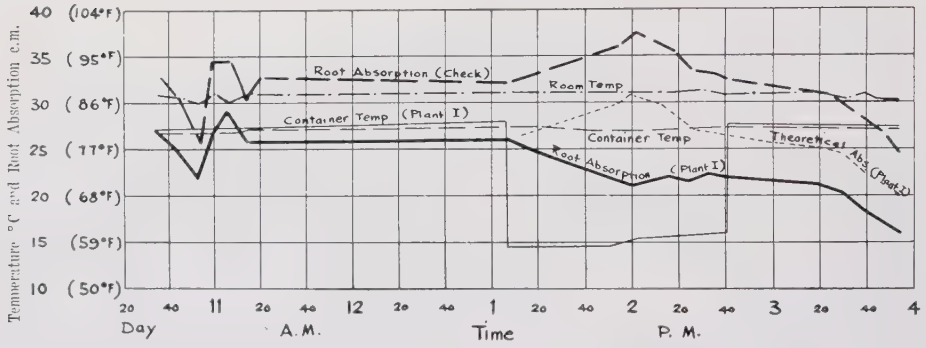


Chart V

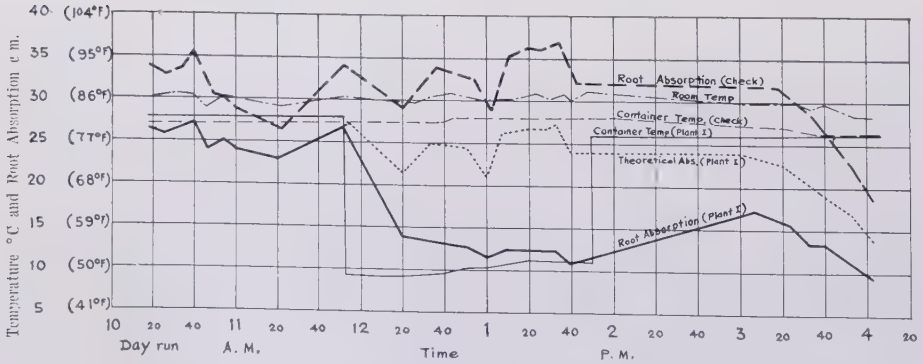


Chart VI

The temperature in Chart VI was lowered to an average of approximately 10° C. (50° F.). Here we find a correspondingly greater response due to the greater drop in temperature. It is interesting to notice that the root absorption of the check plant from 12:20 to 1:40 shows too distinct maximums which are probably due to fluctuations in the light. The plant with roots at the lowered temperature also shows the effect of the light but to a much less degree because the root temperature has evidently become the controlling factor.

It would seem that the roots were more or less permanently affected by this last fall in temperature, as root absorption was farther off from the normal after the temperature was raised than in any previous run.

Summary

1. The relative root absorption of two sugar cane plants growing in water was measured at the same root temperature and with one at normal and the other at several lowered temperatures.

2. With roots at the same temperatures the absorption curves of the two plants followed each other very closely in spite of large fluctuations. These fluctuations were probably for the most part due to the effect of light on transpiration, because they coincide with observations on the light intensity made simultaneously.

3. Light is not wholly responsible for these irregularities in the curves, however, since runs made at night under electric light still show minor ones.

4. These night runs show much less absorption, about one-fifth that of the day runs.

5. Lowering the temperature of the water surrounding the roots from 28° C. to 21° C., 15° C. and 10° C., or from 81° F. to 71° F., 59° F. and 50° F., causes progressively greater decreases in the water absorbed by the roots.

6. Roots which had been subjected to the temperature of 59° F. (Chart V) and 50° F. (Chart VI) had not recovered their former absorption rate two hours after the temperature had been raised to the original 81° F.

It is hoped that work of this sort can be continued so that a curve of root absorption at various temperatures may be worked out.

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A Further Study of the Influence of Weather on Yield

By U. K. Das

Abstract

From an analysis of the yields of the Pepeekeo Sugar Company we find:

(1) That in the last twenty years there has been a marked trend towards increasing yield of cane and sugar per acre and an equally marked but less steep trend towards decreasing quality of juice (Fig. 1).

(2) That, assuming the trends are influenced by our agriculture, the abrupt yearly fluctuations from the trend line are predominantly influenced by the conditions of temperature and rainfall.

(3) That partial regression equations developed from the trend and the weather data will give a satisfactory estimate of yields several months ahead of the grinding season.

(4) That greater use may be made of our weather data to modify our field practices, so that we shall be working with the weather conditions and not against them.

Introduction

In previous weather studies (1, 2, 3) we brought out the general relation between such weather factors as temperature, rainfall and sunshine and the yields of some of our typical plantations; but, therein, we made no attempt to study the separate effect of any of these factors or the combined effect of a number of these factors. In the present paper we propose to make such a study.

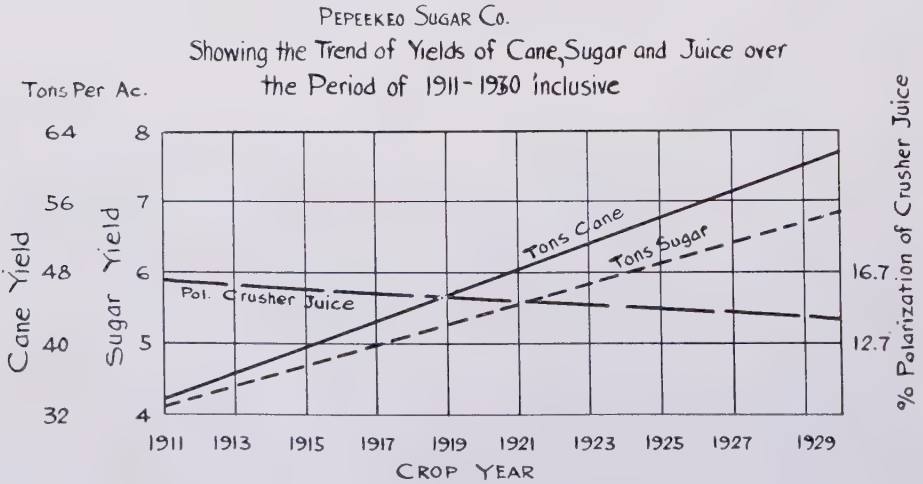

Fig. 1

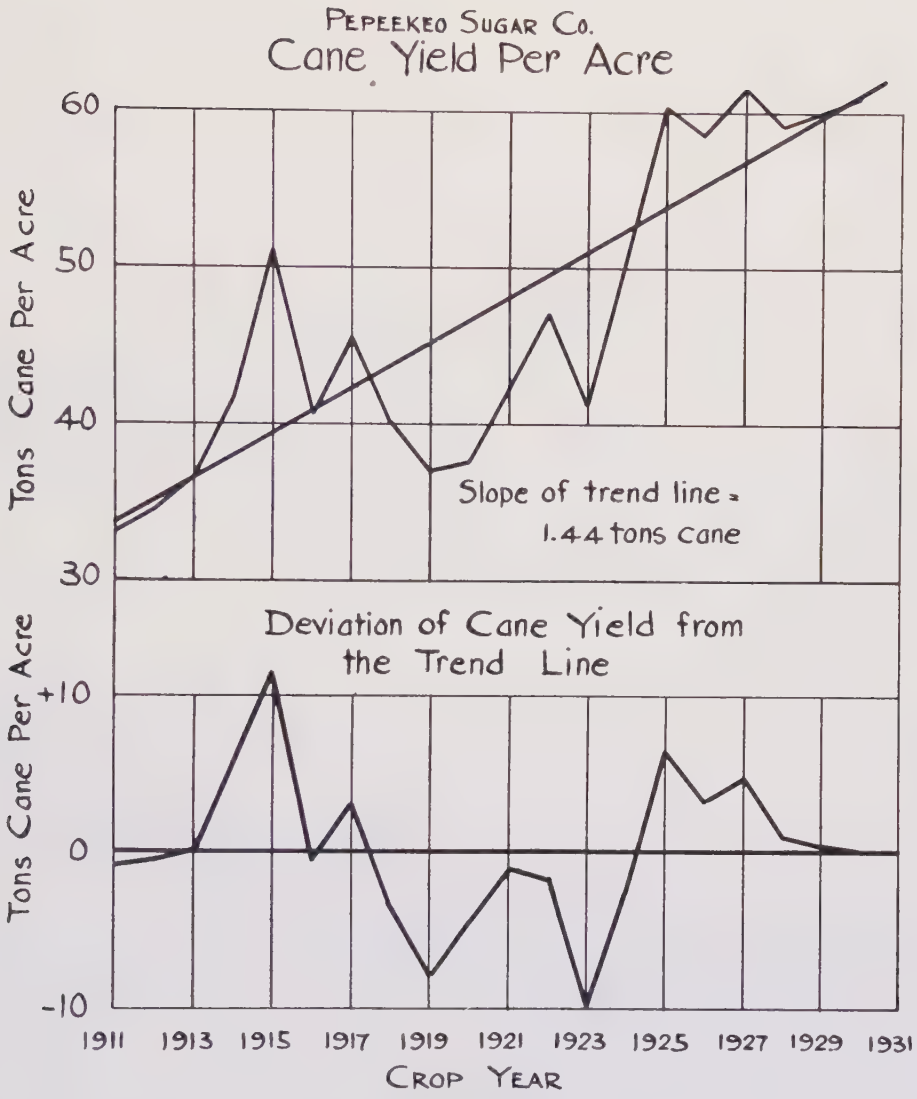

Fig. 2

Subject of Study—Pepeekeo Yields

The yields of the Pepeekeo Sugar Company (1911-1930, inclusive) form the subject of this study. Pepeekeo would appear to be almost an ideal place for a study such as we propose, firstly because it is an unirrigated plantation depending entirely on rainfall for moisture supply, and, secondly, because at Pepeekeo the land area, the fields, the variety of cane and the length of crop have remained practically the same in the 20-year period herein studied.

The first part of this study deals with the yield of cane per acre from year to year, and the second part, the quality of crusher juice. The figures for cane yield include long crops only, but the juice figures include short ratoons as well.

Eliminating the Influence of Secular Trend

Table A and Fig. 2 show the yield of cane from 1911 to 1930. Two facts are discernible in Fig. 2. First, the trend of steadily increasing yields as years pass, and second, the abrupt fluctuations from year to year superimposed on this trend. In the past 20 years there have been marked improvements in our agricultural

TABLE A

Crop Year	Cane Yield Tons Cane	Pol % of Crusher Juice	Crop Year	Cane Yield Tons Acre	Pol % of Crusher Juice
1911	32.95	15.69	1921	47.02	14.53
1912	34.61	15.93	1922	47.92	14.19
1913	36.57	16.57	1923	41.29	14.89
1914	41.46	16.30	1924	50.12	15.22
1915	51.03	15.59	1925	60.37	14.62
1916	40.40	15.89	1926	58.69	15.00
1917	45.40	15.91	1927	61.62	13.54
1918	39.96	15.14	1928	59.19	14.17
1919	37.09	15.67	1929	60.12	14.40
1920	42.09	15.65	1930	61.17	13.79
			1931		14.26*

TABLE B

DEVIATIONS FROM THE TREND LINE OF CANE YIELD PER ACRE AND OF POLARIZATION PER CENT CRUSHER JUICE

	Slope of Trend Line =+1.44 Tons Cane			Slope of Trend Line =—.118 Per Cent Pol.		
Year	Actual Cane Yield	Trend Value	Deviation from the Trend	Actual Polarization	Trend Value	Deviation from the Thend
1911	32.95	33.76	— .81	15.69	16.27	—.58
1912	34.61	35.20	— .59	15.93	16.15	—.22
1913	36.57	36.64	— .07	16.57	16.03	+.54
1914	41.46	38.08	+ 3.38	16.30	15.92	+.38
1915	51.03	39.52	+11.51	15.59	15.80	—.21
1916	40.40	40.96	— .56	15.89	15.68	+.21
1917	45.40	42.40	+ 3.00	15.91	15.56	+.35
1918	39.96	43.84	— 3.88	15.14	15.44	—.30
1919	37.09	45.28	— 8.19	15.67	15.33	+.34
1920	42.09	46.72	— 4.63	15.65	15.21	+.44
1921	47.02	48.18	— 1.16	14.53	15.09	—.56
1922	47.92	49.62	— 1.10	14.19	14.97	—.78
1923	41.29	51.06	— 9.77	14.89	14.85	+.04
1924	50.12	52.50	— 2.38	15.22	14.74	+.48
1925	60.37	53.94	+ 6.43	14.62	14.62	000
1926	58.69	55.38	+ 3.31	15.00	14.50	+.50
1927	61.62	56.82	+ 4.80	13.54	14.38	—.84
1928	59.19	58.26	+ .93	14.17	14.26	—.09
1929	60.21	59.70	+ .51	14.40	14.15	+.25
1930	61.17	61.14	+ .03	13.79	14.03	—.24
1931				14.26	13.91	+.35

practices, and, therefore, it would seem reasonable to assume that the trend reflects our agricultural progress, while the fluctuations from year to year, the progress

* Crop not finished.
Pol figures include data up to August 22, 1931 only.

of weather.* For this reason we need to eliminate the influences of secular trend, before we proceed to analyze the influences of weather.

Fig. 2 shows that the correlation between time (i. e., years elapsed since 1911) and the yield is positive and linear. We may, therefore, treat time as a variable and determine the coefficient of regression of time on cane yield or, in other words, determine the average increase in yield corresponding to the passage of a year's time. (Appendix A.)

The trend line thus determined (Fig. 2) shows that beginning at 33.76 tons of cane per acre in 1911, the yield increases on the average by 1.44 tons of cane a year.

The departures of the actual yields from this trend line may now reasonably be attributed to weather influences. These departures are shown in Table B and Fig. 2.

Obtaining the Coefficients of Correlation

We next proceed to obtain the coefficients of correlation between the departures of cane yield and the departures of rainfall or temperature. As the crops under consideration were all about 23 to 24 months old, the coefficients are obtained for all the months during which a crop has been in the field. For this purpose we assume that an average crop, say 1930, starts in July of 1928, and is harvested 23 to 24 months later, i. e., in April or May of 1930. We also assume that an average yield is obtained under conditions of average weather and that under the conditions of Pepeekeo the relation between temperature, rainfall and cane growth is linear.

TABLE C

COEFFICIENTS OF TOTAL CORRELATION BETWEEN CANE YIELD AND VARIOUS WEATHER FACTORS

	Mean Maximum Temperature and Yield	Mean Minimum Temperature and Yield	Rainfall and Yield
1st Season:			
July	+.36	+.18	.....
August	+.37	+.56	+.03
September	+.68	+.37	+.10
October	+.64	+.50	+.06
November	+.45	+.30	—.01
December	+.40	+.51	—.04
2nd Season:			
January	+.47	—.05	—.32
February	+.45	+.09	—.55
March	+.55	+.04	—.63
April	+.49	+.12	—.43
May	+.39	+.22	+.45
June	+.23	+.41	+.28
July	+.22	+.48	+.09
August	+.18	+.45	+.67
September	+.21	+.45	+.34

* The trend line may also be influenced to a certain extent by a trend in weather conditions. Preliminary examination of the data, however, fails to show any marked trend in weather.

TABLE C—Continued

	Mean Maximum Temperature and Yield	Mean Minimum Temperature and Yield	Rainfall and Yield
October	+.35	+.02	+.06
November	+.52	+.26	—.06
December	+.43	+.26	+.03
Harvesting Season:			
January	+.48	+.13	—.38
February	+.27	—.08	—.26
March	+.50	+.15	—.33
April	+.49	—.03	—.03
2nd Season:			
January to March (combined)			—.63

Meaning of the Correlation Coefficient

The correlation coefficient is a mathematical symbol which shows at a glance the nature and the extent of the relation between two quantities. The coefficient can be anything from —1 to +1. Both the sign and the magnitude of the coefficient are of significance. A plus sign means a positive correlation between the quantities, i. e., an increase or decrease in one is associated with an increase or decrease in the other. A minus sign shows a negative correlation, i. e., an increase in one is associated not with an increase but with a decrease in the other and vice versa. The coefficient is zero when there is no relation whatsoever between the two quantities and —1 or +1 when there is perfect agreement between the two.

Rarely ever in practice does one find a perfect correlation, but it is generally agreed that where the number of pairs correlated is 20 (20 years of crop and weather data in our case) then a coefficient of .50 or over may be accepted as showing a marked relation between the correlated items.

In weather and crop studies, the periods showing such marked relation are often termed "critical periods," implying thereby that the crop is likely to be permanently affected by the conditions of weather prevailing during these critical periods. For a better understanding of our crop, we need, therefore, to know the duration as well as the importance of these critical periods.

Discussion of Results

The coefficients of correlation are presented in Table C and Fig. 3.

Temperature: We have considered two measures of temperature, namely, mean monthly maximum and mean monthly minimum temperature. We believe that a study of these two measures separately will give us a better understanding of the growth processes of cane than a study of mean temperature alone.

Fig. 3 shows that as regards maximum temperature, all the months show positive correlation to cane yield; in other words, high maximum temperature always tends to increase the cane yield. The same is more or less true of minimum temperature. We may, therefore, conclude that at Pepeekeo temperature is definitely a limiting factor.

In Fig. 3, we also note that while all the months show positive relation between maximum temperature and cane yield there are only three months which appear

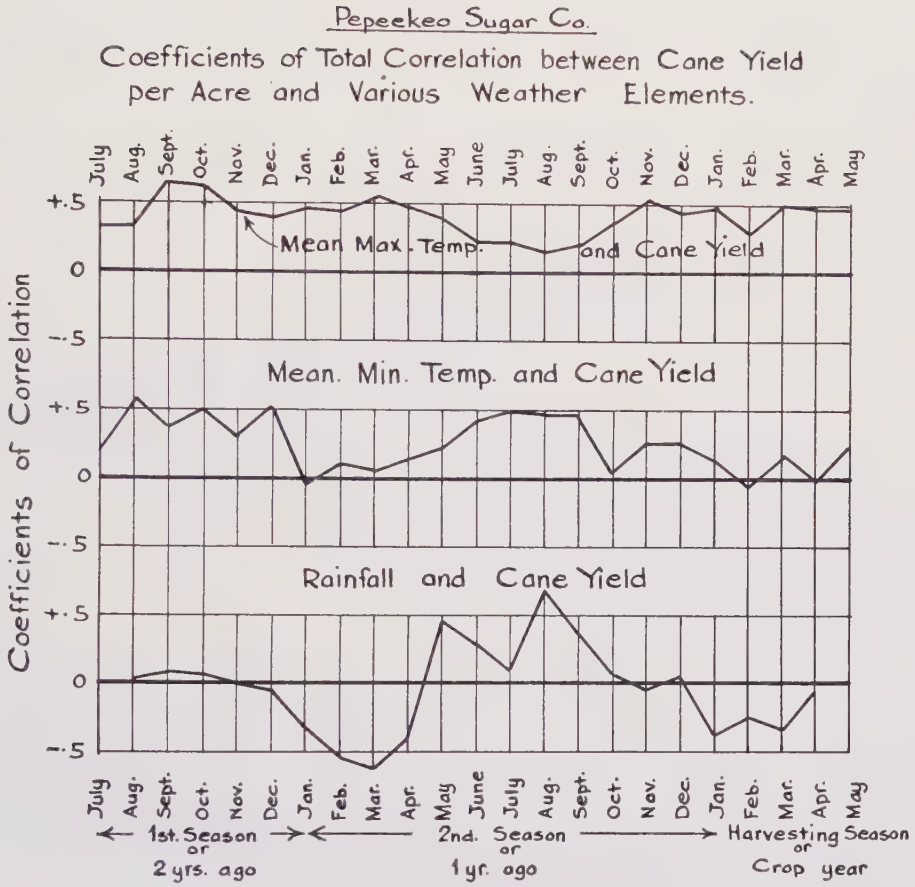
Pepeekeo Sugar Co.
Coefficients of Total Correlation between Cane Yield per Acre and Various Weather Elements.
July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May
+.5
0
-.5
Coefficients of Correlation
Mean Max. Temp. and Cane Yield
Mean. Min. Temp. and Cane Yield
Rainfall and Cane Yield
1st. Season or 2 yrs. ago
2nd. Season or 1 yr. ago
Harvesting Season or Crop year

Fig. 3

to have "critical" significance. These are the fall months of September, October of the first season, and the month of March of the first winter of crop growth. This is in perfect agreement with the conclusions arrived at in our preliminary study of the sugar yields of this plantation.

These critical periods lend support to the increasing realization that the first several months in the life of a crop are of the greatest moment, because it is in the first few months that the stand is being established, and it is in this period that the cane is growing by nature at a rapid rate. Conditions of temperature at this period of formation and rapid growth affect the crop to a greater degree than at any subsequent period.

The high positive coefficient of correlation for March of the first winter probably reflects the injurious effect of Pepeekeo winters, which are generally wet and cold.

Rainfall: Fig. 3 shows that high yields are correlated with low rainfall in the first winter and high rainfall in the second season summer, and low rainfall again in the grinding season. The importance of the two latter periods are generally recognized, but not so the extremely injurious effects of excessive rain in the first winter. The harmful effects of wet first winter may be as follows: First, high

rainfall lowers the temperature; second, probably it saturates the soil, driving out all air, and giving rise to a very unhealthy physical condition; third, coming about the time when second season application of nitrogen is being made, high rainfall probably causes a great loss of nitrates from the soil.

The critical periods appear to be the entire period of January to March of the first winter and the month of August of the second season summer.

In drawing repeated attention to these critical periods, we do not imply that the conditions in the other months are of no consequence, but we simply suggest that under normal conditions of weather, the other periods pretty well take care of themselves so long as the critical periods are as desired.

The Combined Effect of Weather—Multiple Correlation

The coefficients of correlation obtained thus far show that cane yield at Pepeekeo is markedly influenced by temperature in the fall months of the first season and rainfall in the first winter and also in the month of August of the second season summer. These coefficients do not, however, tell us of the relative importance of these periods, neither do they show as to what proportion of the total variation from year to year can reasonably be accounted for by the weather conditions in these critical periods. What we need, therefore, to know is the partial correlation between temperature or rainfall and yield (i. e., the independent correlation of any of these factors with yield when the other factors are kept constant) and, then, the multiple correlation, or, in other words, the combined effects of all of these factors on yield.

Following the methods developed by Yule (4) we have worked out the partial and the multiple coefficients and also the regression equation showing the relation between yield, temperature and rainfall.

The coefficient of multiple correlation, after adjusting for the paucity of our data, is 0.89. The square of the multiple coefficient, otherwise known as the coefficient of determination (R^2), is said to measure the percentage of total variation accounted for by the factors combined. In the present case, $R^2=0.79$, that is, about 79 per cent of the total variation in the yield of cane from year to year at Pepeekeo can reasonably be attributed to the influence of rainfall and temperature (or others associated with these two factors). The coefficient of determination would probably be greater if other aspects of weather were taken into consideration.

Weather conditions thus appear to be the biggest factor in causing the tremendous yearly fluctuations in yield.

The regression equation is as follows:

$$D=0.781t-0.107r_w+0.437r_s$$

Where D=departure of cane yield (in tons per acre) from the trend line.

t=deviation from the average of mean maximum temperature (F°) in October, first season.

r_w=deviation from average of inches rainfall in January, February and March of the first winter.

r_s=deviation from average of inches rainfall in August of second season summer.

TABLE D

ACTUAL YIELD OF CANE AND THE YIELD CALCULATED BY THE PARTIAL REGRESSION EQUATION

Crop Year	A Departures Calculated from the Equation	B Actual Departures from the Trend Line	C Trend Line Values	D Calculated Yield of Cane (A + C)	E Actual Yield of Cane	Difference Between Actual and Estimated Yields (E — D)
1911	— .69	— .81	33.76	33.07	32.95	— .12
1912	— 1.43	— .59	35.20	33.77	34.61	+ .84
1913	+ .27	— .07	36.64	36.91	36.57	— .34
1914	— 1.91	+ 3.38	38.08	36.17	41.46	+5.29
1915	+11.32	+11.51	39.52	50.84	51.03	+ .19
1916	+ .37	— .56	40.96	41.33	40.40	— .93
1917	+ 2.75	+ 3.00	42.40	45.15	45.40	+ .25
1918	— 1.91	— 3.88	43.84	41.93	39.96	—1.97
1919	— 6.95	— 8.19	45.28	38.33	37.09	—1.24
1920	— .42	— 4.63	46.72	46.30	42.09	—8.65
1921	— 4.81	— 1.16	48.18	43.37	47.02	—1.28
1922	— 4.37	— 1.70	49.62	45.25	47.92	+1.77
1923	— 7.70	— 9.77	51.06	43.36	41.29	—2.07
1924	— 2.53	— 2.38	52.50	49.97	50.12	+ .15
1925	+ 3.31	+ 6.43	53.94	57.25	60.37	+3.12
1926	+ 1.10	+ 3.31	55.38	56.48	58.69	+2.21
1927	+ 5.83	+ 4.80	56.82	61.65	61.62	— .03
1928	+ .39	+ .93	58.26	58.65	59.19	+ .54
1929	+ .91	+ .51	59.70	60.61	60.21	— .40
1930	— .63	+ .03	61.14	60.51	61.17	+ .66
1931*	+ 5.83					
1932*	+ 4.33					

The actual departures of yield and the departures calculated by our equation are shown in Table D and Fig. 4. The agreement of the two sets of figures is very striking.

The error of estimate calculated from the coefficient of multiple correlation is 2.5 tons of cane. In other words, if we were to form an estimate of cane yield departures from the temperature and rainfall data of the three critical periods and if other factors in production remained the same, then our estimate would come within 2.5 tons of the actual yield in about 67 per cent of cases, or within 5 tons of the actual in 95 out of 100 cases. Surely no empirical manner of estimating would yield results that would agree so well with the actual.

This regression equation can easily be transformed so as to give yields in actual tons per acre rather than as departures from the trend line. What we need to do is simply to add the equation for the trend line. The transformed equation is as follows:

* These two crops were not included in the original study. These figures are, therefore, in the nature of a prediction of yields from weather data.

Cane Yield $=33.76+1.44Y+0.781t-0.107r_w+0.437r_s$ in tons per acre

Where Y = number of years elapsed since 1911, the other symbols have the same meaning as in the first equation.

The actual yield of cane per acre and the yield calculated from the new equation are also given in Table D and Fig. 4. The degree of agreement between the actual and the calculated yields is even closer in this Fig. 4.

The coefficient of correlation between years elapsed since 1911 and yield of cane is 0.86. The coefficient of determination is .74. If 74 per cent of the total variation between 1911 and 1930 is accounted for by the progressive trend, we are left with about 26 per cent to be accounted for by weather. We have seen that temperature and rainfall account for about 80 per cent of the variations left over

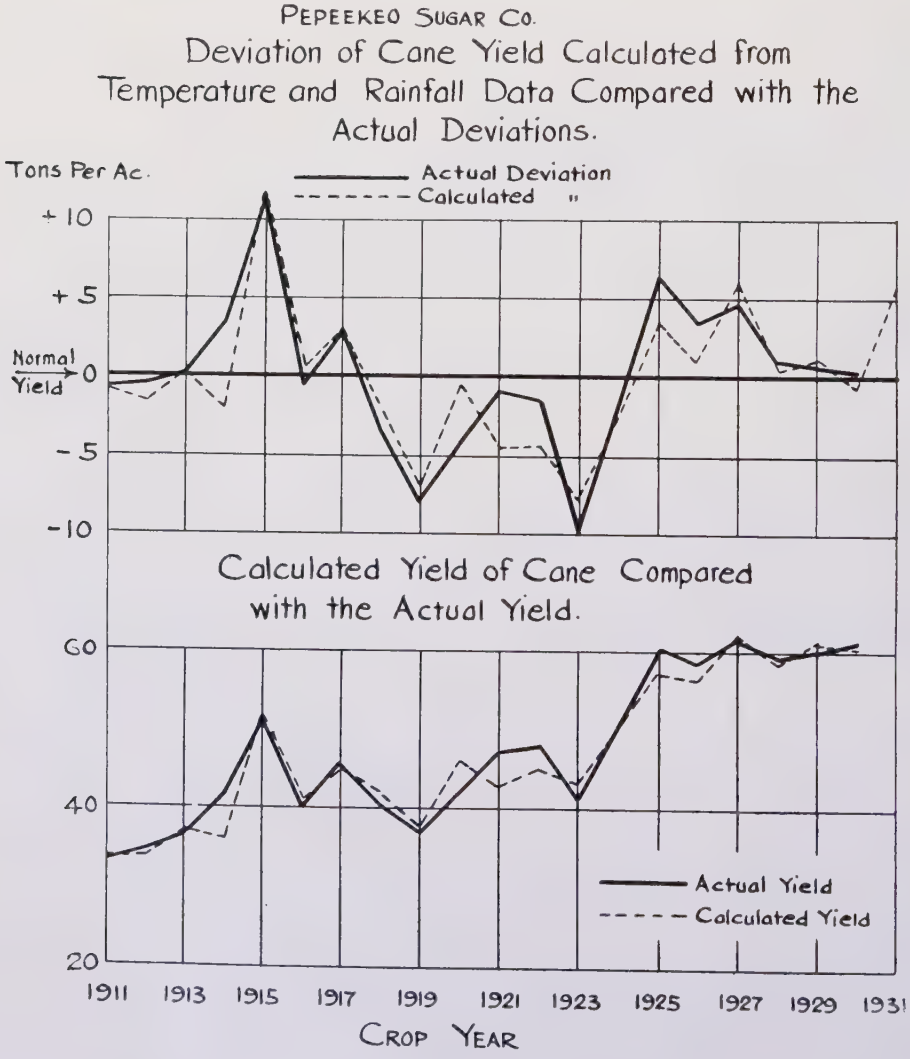

Fig. 4

after eliminating the trend line. Temperature and rainfall, therefore, account for 80×26 or fully 20 per cent of the total variation. Trend line and weather conditions together account for nearly 94 per cent of the total variations in yield at Pepeekeo for 1911 to 1930, leaving only 6 per cent to be accounted for by other causes.

Relative Importance of Temperature and Rainfall

The regression equations show that every degree of temperature above the average in October of the first season increases the yield by 0.781 ton of cane, while one inch of rainfall in August increases yields by only 0.437 ton. One degree of temperature above average would, therefore, be worth 179 per cent as much as one inch of rainfall above average. While this is true, the Pepeekeo records show that temperature deviations never exceeded 5 degrees while rainfall deviation in August was as high as 19 inches. The rainfall variations are, therefore, of greater practical interest at Pepeekeo than the variations of temperature.

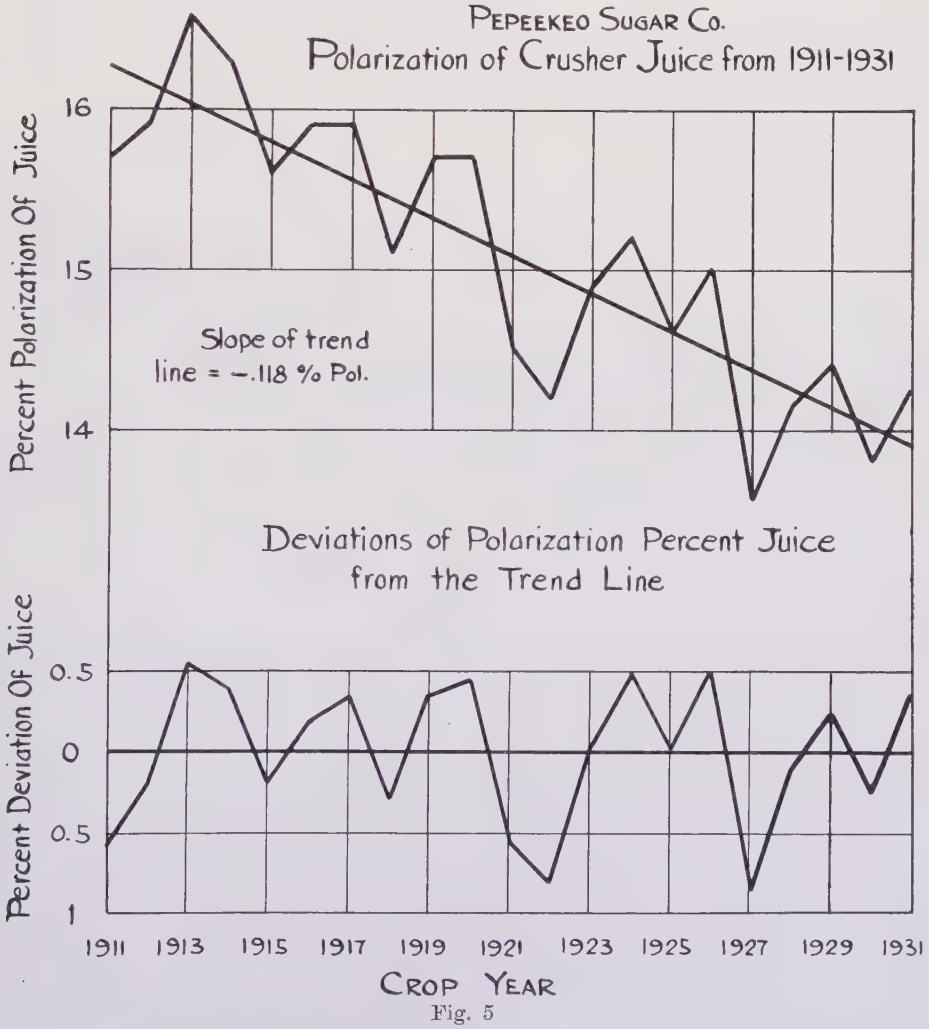

Fig. 5

The loss in cane yield due to an additional inch of rain in the first winter is only 0.107 ton. Therefore high rainfall in the month of August is of greater importance than low rainfall in the first winter.

Juice Quality

Table A and Fig. 5 show the polarization per cent crusher juice from 1911 to 1930. We see in Fig. 5 that whereas in cane yield there was a marked upward trend, in the quality of juice there is an equally marked trend downwards. In this case also, the trend appears to be a straight line. We have accordingly calculated the regression of time on yield as we did in the case of cane yield. The equation of trend line is: Per cent Pol of Juice=16.27—0.118Y.

Where Y=number of years elapsed since 1911.

The departures from this trend are then correlated with temperature and rainfall data.

TABLE E

COEFFICIENTS OF CORRELATION BETWEEN POLARIZATION PER CENT CRUSHER JUICE AND VARIOUS WEATHER FACTORS

	Mean Maximum Temperature	Mean Minimum Temperature	Mean Daily Range of Temperature	Monthly Rainfall
1st Season:				
August	+.35	+.14	+.18	—.03
September	+.28	+.05	+.23	00
October	+.23	+.04	+.13	—.06
November	+.18	+.16	+.12	+.39
December	+.15	—.01	+.16	+.06
2nd Season:				
January	+.14	—.14	+.23	+.01
February	+.07	—.04	+.16	+.13
March	—.20	—.11	—.15	+.20
April	—.11	—.06	—.07	+.49
May	—.09	—.25	+.03	+.17
June	+.15	—.14	+.22	+.34
July	+.18	+.13	+.11	+.03
August	+.21	+.07	+.15	—.12
September	+.30	+.33	+.07	+.09
October	+.36	+.29	+.24	+.04
November	+.10	+.11	+.06	+.05
December	+.13	+.24	+.06	—.03
Harvesting Season:				
January	+.18	—.02	+.19	—.25
February	+.10	—.15	+.16	—.33
March	+.28	—.29	+.40	—.41
April	+.21	—.37	+.35	—.41
May	+.23	—.07	+.28	—.09

Discussion of Results

The coefficients of correlation are shown in Table E and Fig. 6.

Temperature: From the trend of the values of correlation coefficient in Fig. 6 we conclude that for good juice mean maximum temperature should generally

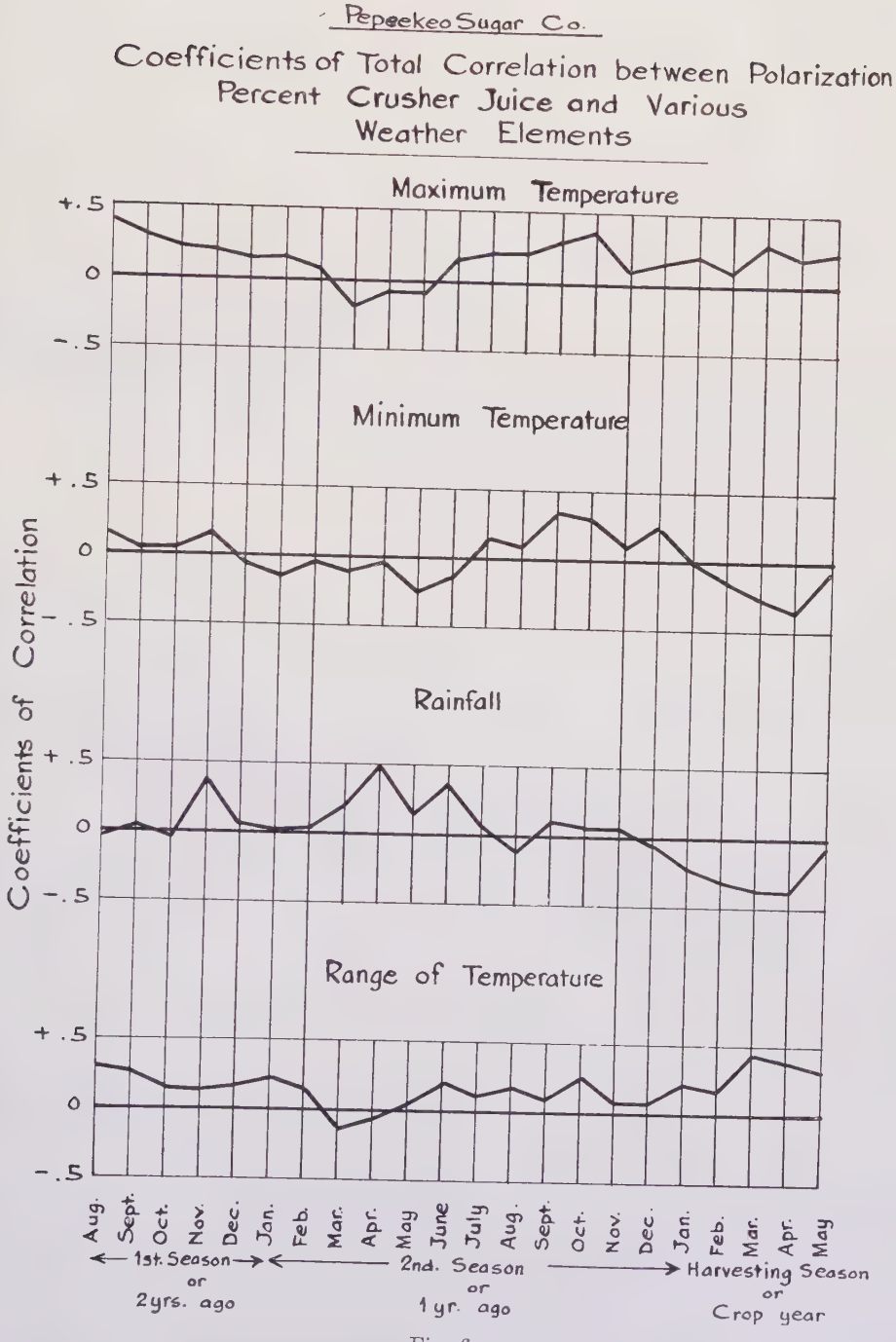
Pepeekeo Sugar Co.
Coefficients of Total Correlation between Polarization Percent Crusher Juice and Various Weather Elements
Maximum Temperature
Minimum Temperature
Rainfall
Range of Temperature
+.5
0
-.5
Coefficients of Correlation
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
1st. Season
or
2yrs. ago
2nd. Season
or
1 yr. ago
Harvesting Season
or
Crop year

Fig. 6

be above the average, except possibly in the spring months of the second season, and minimum temperature should generally be lower than the average except in the summer and fall months. During the ripening and harvesting season particularly we should have low minimum temperatures and high maximum temperatures. As high maximum temperature is believed to be an index of bright, sunny days and low minimum temperature of cool, clear nights, the coefficients indicate that good juices are likely to be obtained if the days are bright and sunny and the nights cool during the ripening season. This is in agreement with our conclusions deduced from a study of the juice quality of the Ewa Plantation Company (3).

Range of Temperature: Daily range of temperature is the difference between the daily maximum and daily minimum temperature. High range of temperature generally signifies bright days with high maximum temperature, and clear and cool nights with low minimum temperature.

The coefficients of correlation in Table E and Fig. 6 show that good juices are generally associated with high range of temperature during the entire period of crop growth.

This bears out the conclusion arrived at in our previous studies, that range of temperature has a pronounced effect on juice quality.

However, neither maximum or minimum temperature nor range of temperature show any "critically" significant relation to juice quality, from which we conclude that probably there are other factors which exercise a greater influence on the quality of juice at Pepeekeo than temperature.

Rainfall: The trend of values of these coefficients (Fig. 6) indicates an increasing demand of additional rain till the month of April in the second season, and from then on the demand tapers off in much the same way as the application of water is tapered off on the irrigated plantations. In the harvesting season high rainfall is found to be highly detrimental.

The harmful effects of excessive rainfall in the grinding season are very generally recognized, but we have heard very little as yet as to the beneficial effects of high rainfall in the winter and spring months of the second year. The trend of the coefficients is so definite that we feel that here we are face to face with a genuine weather and crop relation. The following is offered as a possible explanation of the significant relation between high rainfall in the spring months of the second season and juice of high quality.

At Pepeekeo the second season application of nitrogen is generally made in the months of March and April. We have suggested elsewhere in our studies (5) that there are good reasons to believe that the generally poor juices obtained nowadays as compared with 10 or 20 years ago are probably due in a large measure to increasing applications of soluble nitrogen, especially the application in the second season. It is our belief that fields of cane fed with large quantities of nitrogen do not generally reach full maturity at the time they are harvested.

If these considerations are justified, it would appear that any factor that tends to withdraw the nitrogen from the soil or make it more easily assimilated by the plant, that factor would thereby cause an improvement in the quality of juice.

High rainfall in the second season spring may be a factor of the same nature. It probably leaches out a substantial amount of the nitrogen from the soil, or by

encouraging cane growth causes most of the nitrogen to be taken up early in the season. If the weather at this period were dry, the nitrogen would, probably, stay in the soil to be taken up later in the season, perhaps too late in the season to yield cane of good maturity.

The actual sequence of rainfall in a group of four years in which juice quality was much above the average and in another group of four years in which the quality was much below, is shown in Fig. 7.

TABLE F

ACTUAL POLARIZATION OF CRUSHER JUICE AND THE POLARIZATION OF JUICE CALCULATED BY THE REGRESSION EQUATION

Crop Year	A Departures Calculated from the Equation	B Actual Departures from the Trend Line	C Trend Line Values	D Calculated Pol of Juice	E Actual Pol of Juice	(E — D) Difference Between the Actual and Calculated Pol
1911	—.11	—.58	16.27	16.16	15.69	—.47
1912	—.08	—.22	16.15	16.07	15.93	—.14
1913	+.32	+.54	16.03	16.35	16.57	+.22
1914	+.02	+.38	15.92	15.97	16.30	+.33
1915	—.27	—.21	15.80	15.53	15.59	+.06
1916	+.28	+.21	15.68	15.96	15.89	—.07
1917	+.01	+.35	15.56	15.57	15.91	+.34
1918	—.52	—.30	15.44	14.92	15.14	+.22
1919	+.25	+.34	15.33	15.58	15.67	+.09
1920	—.18	+.44	15.21	15.03	15.65	+.62
1921	—.30	—.56	15.09	14.79	14.53	—.26
1922	—.15	—.78	14.97	14.82	14.19	—.63
1923	—.18	+.04	14.85	14.67	14.89	+.22
1924	+.45	+.48	14.74	15.19	15.22	+.03
1925	—.05	00	14.62	14.57	14.62	+.05
1926	+.49	+.50	14.50	14.99	15.00	+.01
1927	—.33	—.84	14.38	14.05	13.54	—.51
1928	+.26	—.09	14.26	14.52	14.17	—.35
1929	—.22	+.25	14.15	13.93	14.40	+.47
1930	—.36	—.24	14.03	13.67	13.79	+.12
1931	+.58	+.35	13.91	14.49	14.26	—.23
1932						

Calculation of Juice Quality From Weather Data

As in the case of cane yields here we have calculated the coefficient of multiple correlation between the percentage of polarization of crusher juice and the various weather data.

The highest coefficient of multiple correlation obtained after trying out several combinations is 0.69. The coefficient of determination ($=R^2$) is only .47. In other words, only about half the variations in the juice quality from year to year could be attributed to weather conditions.

It is quite probable that the fluctuations in the per cent polarization of crusher juice are influenced by many other causes of which we know very little at present.*

* One source of trouble may be the inclusion of short ratoons in the juice figures of some recent years. A small area of short ratoons yielding poor juices may lower the average juice figure for the whole crop.

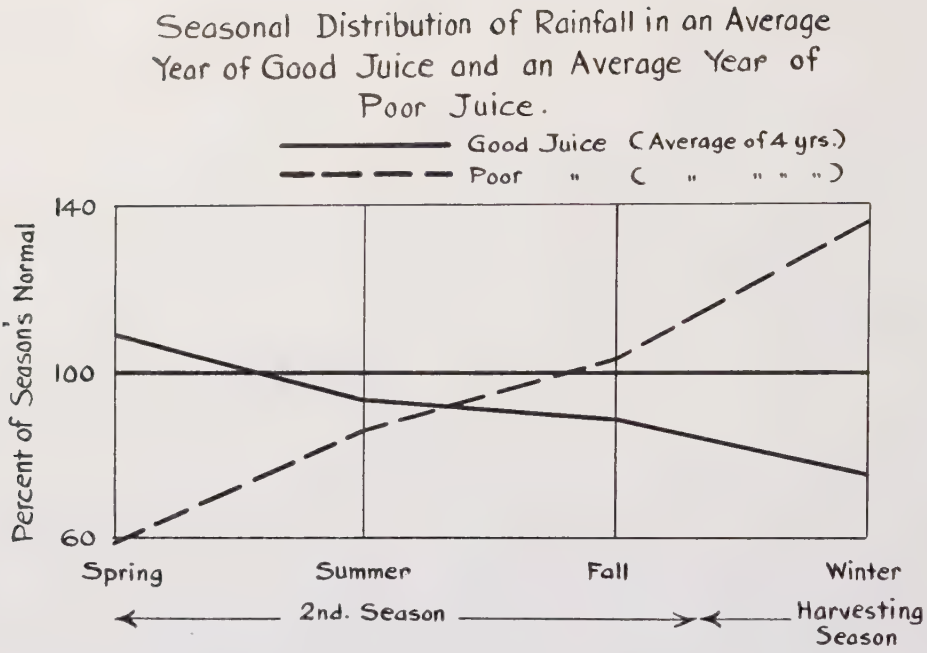

Fig. 7

The equation connecting polarization of juice with weather data is as follows:

$D = 0.029r_1 - 0.022r_2 + 0.056$ r.t

Where D=deviation from the trend line of per cent polarization of crusher juice,

r_1=deviation from average of inches rainfall in April of the second season spring,

r_2=deviation from the average of inches rainfall in April of the grinding season,

r.t=deviation from average of range of temperature in March of the grinding season.

By adding the equation of the trend line to this equation, we obtain as before a new equation from which we can calculate the actual percentage of polarization. The new equation is as follows:

Per cent Pol of Crusher Juice $= 16.27 - 0.118Y + 0.029r_1 - 0.022r_2 + 0.056$ r.t; where Y is the number of years elapsed since 1911.

The new equation (trend and weather factors combined) accounts for only 86 per cent of the total variation from 1911 to 1931. The prediction value of this equation is, therefore, not nearly as good as is the equation obtained in the case of cane yield.

The calculated and the actual figures are shown in Table F and Fig. 8. We note that the greatest divergence of the actual and the calculated yield is obtained for the crop of 1920. In checking up the month to month progress of rainfall, we

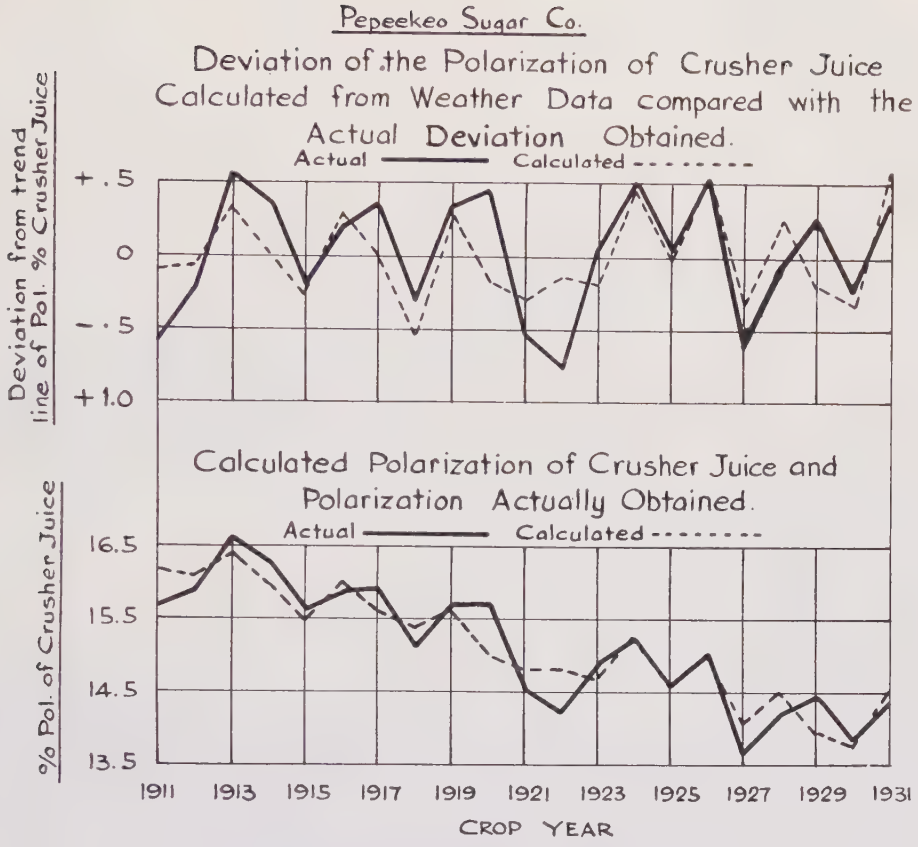

Fig. 8

find that the distribution of rainfall for the crop of 1920 was quite abnormal. Under normal conditions of weather, the sequence of seasons is such that deficiency of rainfall in one season is usually followed by an excess in the other season, so that the sum total for the crops tends to be about the same. However, in the case of the crop of 1920, one dry month followed another for almost a year prior to harvest. Theoretical considerations would suggest that if high rainfall in the second season spring improves juices by withdrawing nitrogen from the soil at an early period, the same effect could be secured by a succession of dry months so that the nitrogen would remain in the soil without being taken up by the cane plant in large quantities and hence doing no harm to the quality of juice. If we eliminate the figures for 1920 as being incomparable with the rest of the period and recalculate the regression equations we find that the accuracy of our estimate is greatly increased.

We offer the following theory as to the effect of rainfall on juice quality at Pepeekeo, and present the same information graphically in Fig. 9:

1. High rainfall in the spring of second season followed by gradually diminishing rainfall ending in a dry grinding season. Excellent juice.

2. A consistently dry season. Good juice. (Probably poor cane yield.)

Pepeekeo Sugar Co.

Diagrammatic Representation of the Influence of Rainfall in the Spring of the Second Season and the Winter of the Harvesting Season.

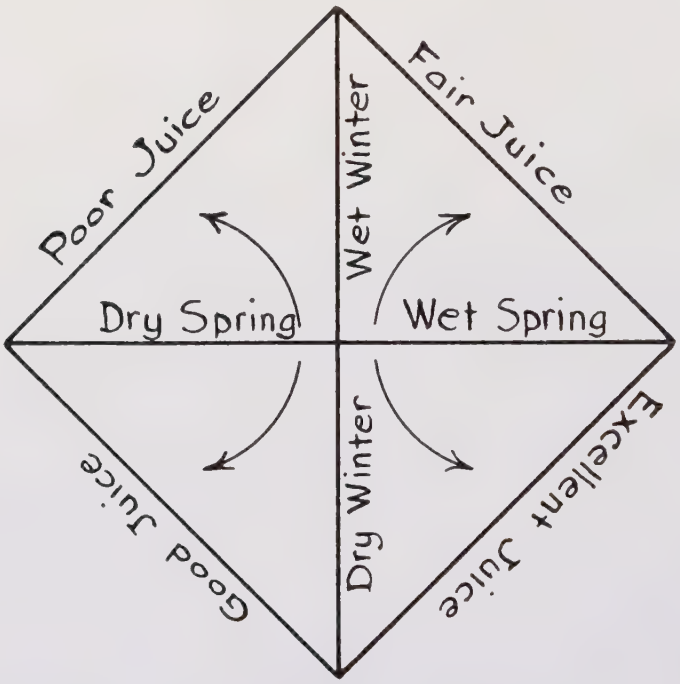

Fig. 9

3. High rainfall in the spring of second season followed by high rainfall in the other seasons including the grinding season. Fair juice.

4. Low rainfall in the spring of second season followed by increasing amounts of rain ending in a wet harvesting season. Very poor juice.

In other words, from the present study we are inclined to think that high rainfall in the second season spring months (under the conditions of our present day field practices) is of greater moment than a dry harvesting season. If the cane has grown vigorously in the spring and summer months of the second season and thereby used up the easily available stores of nitrogen, then it will enter the grinding season in a state of good maturity. Under these conditions a wet grinding season will not cause much damage if a large amount of new growth is not started by a simultaneous occurrence of good growing temperature.

However, this study leaves no room for doubt that at Pepeekeo rainfall is the greatest single factor in causing yearly fluctuations in the quality of juice.

Practical Application of the Results of Weather Studies

The detailed studies of the relation of weather to cane crop do not only furnish us with much valuable fundamental knowledge, but quite often they also suggest possible modifications of field practices whereby greater advantage may be taken of the weather conditions.

In dealing with cane yield, we pointed out the critical importance of the first several months in the life of the cane crop. This would suggest that all our agricultural practices be designed to give the best care and treatment to the crops that are in the first season of growth. Should question arise, as it used to a few years ago, as to which cane should be neglected, there need be little hesitation in choosing to neglect the old cane in preference to the small cane.

Many of us are inclined to think that in a humid district like Pepeekeo with an average rainfall of about 130 inches a year, the moisture requirements of the cane should be amply satisfied. The results of this study show that this is far from the truth and that substantial gains in cane yield could probably be secured if more moisture could be applied to the second season cane in the summer months. However, the practicability as well as the economics of a venture in irrigation (at least on limited areas) must be left to the plantation to decide.

In dealing with the quality of juice, we would suggest that the following modifications be given consideration.

It is the present practice to apply about 75 pounds of easily available nitrogen partly in the month of March and mostly in the month of April of the second season. If the immediately following spring and summer months have well distributed and sufficient rain, the growth of the cane proceeds rapidly and the nitrogen is taken up early in the season. The crop has, consequently, ample time to complete vegetative growth and start maturing. If, on the other hand, rainfall is much below normal, the growth of the crop is slow and the nitrogen stays in the soil. (Some writers (6) suggest that it goes into an organic form during a dry summer to be available again in an inorganic form when the rains come.) Then following a dry spring and summer comes a wet fall or a wet winter, the stores of nitrogen in the soil become available again and the crop puts on a luxuriant growth. But this growth comes too late, the crop has hardly any time to mature before it is being harvested. The question naturally arises: Can we not avoid this state of affairs by taking the weather factors into consideration? These studies suggest two possible ways: First, by applying the second season nitrogen much earlier. But there are reasonable objections to applying nitrogen previous to or during the wet and cold months of January, February and March. Not only are there dangers of excessive leaching, but also it is doubtful if the plant gets full benefit from nitrogen applications in the cold months of the year when growth processes are normally very slow. Second, by modifying our present practice in the following manner: Let us assume that we have decided to apply second season nitrogen not earlier than April. We would then split up our dose of 75 pounds into two lots, one of 50 pounds and another of 25 pounds. We shall apply the first dose in April and if the weather conditions immediately following are favorable to growth, and there is plenty of well distributed rainfall, then we shall apply

the second dose of 25 pounds in June or early July.* With normal rainfall, these and the months following are generally the months of most vigorous growth and, therefore, there will be plenty of time for the cane to assimilate the nitrogen and come to maturity in due course of time.

If, on the other hand, rainfall is far below normal in the months following the spring application and growth of the crop is slow, then we would withhold the second application altogether.

In a season of belated rains shall we not, thereby, prevent the loss of quality in juice and save money in our fertilizer bill as well?

Theoretically there appears no reason to believe that the yield of cane will be materially affected by this modification.

Whether the extra cost of applying the second dose in July will offset the gain in juice quality is still a question to be decided by actual experimentation.

Prediction Value of the Regression Equations

The regression equations developed previously in this study show that at least in the case of the cane tonnage, the probable yield may be estimated with reasonable accuracy several months before the actual harvesting season. The question would be asked: Can this manner of estimating yield replace the present practice of estimating from experience or by the eye alone?

The greatest uncertainty in the use of such an equation would arise from not knowing exactly the direction and magnitude of the future trend. In this study, the trend appears to be continually rising at the average rate of 1.44 tons of cane per acre per year. It is not conceivable that the trend will continue to be the same indefinitely. In fact there are very sound reasons for believing that the trend will or is already flattening out at Pepeekeo. The calculation of actual tons cane per acre from the equation may, therefore, be subject to error. It must be left to the discretion of the people on the plantation as to what value should be given to the trend line.

We believe, however, that if we use these equations to get an idea as to whether our next yield is going to be considerably above, near or below the average, we will find that the accuracy of our estimate will, in general, be better than any other estimate based on experience alone.

For the present, therefore, we do not think that these equations can replace the standing methods of estimating yield, but we strongly believe that these could supplement and aid the methods in vogue.

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* Recent experiments seem to indicate that the total amount of nitrogen at present applied in the Hilo-Hamakua coast plantations may be more than the limit of profitable application. If this is true, the total second season application can be cut down to 50 pounds per acre and then, there need be no occasion to apply a second dose of 25 pounds.

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(4) Yule, G. Udny. 1927. An introduction to the theory of statistics. Chap. XII, pp. 229-253. (Eighth edition, London.)

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APPENDIX—A

DETERMINATION OF THE TREND LINE FOR CANE YIELD (1911-1930)

Crop Year	A Yield of Cane-Tons per Acre	B Years Elapsed Since 1911	dA Deviation from the Mean	dB Deviation from the Mean	dB^2	dA x dB
1911	32.95	0	—14.51	—9.5	90.25	+137.85
1912	34.61	1	—12.85	—8.5	72.25	+109.23
1913	36.57	2	—10.89	—7.5	56.25	+ 81.68
1914	41.46	3	— 6.00	—6.5	42.25	+ 39.00
1915	51.03	4	+ 3.51	—5.5	30.25	— 19.64
1916	40.40	5	— 7.06	—4.5	20.25	+ 31.77
1917	45.40	6	— 2.06	—3.5	12.25	+ 7.21
1918	39.96	7	— 7.50	—2.5	6.25	+ 18.75
1919	37.09	8	—10.37	—1.5	2.25	+ 15.56
1920	42.09	9	— 5.37	— .5	.25	+ 2.69
1921	47.02	10	— .44	+ .5	.25	— .22
1922	47.92	11	+ .46	+1.5	2.25	+ .69
1923	41.29	12	— 6.17	+2.5	6.25	— 15.43
1924	50.12	13	+ 2.66	+3.5	12.25	+ 9.31
1925	60.37	14	+12.91	+4.5	20.25	+ 58.10
1926	58.69	15	+11.23	+5.5	30.25	+ 61.77
1927	61.62	16	+14.16	+6.5	42.25	+ 92.04
1928	59.19	17	+11.73	+7.5	56.25	+ 87.98
1929	60.21	18	+12.75	+8.5	72.25	+108.38
1930	61.17	19	+13.71	+9.5	90.25	+130.25
Mean of 20 years	47.46	9.5		Sum of dB^2=665.0		Sum of (dA x dB)=956.97

$$\text{Slope of the trend line} = +\frac{956.97}{665} = 1.44 \text{ tons cane}$$

Filter Mud and Molasses*

By H. P. Agee

We shall concern ourselves at this time with the use of these materials for agricultural purposes only.

For each 100 tons of cane that we produce we make 2 to 3 tons of filter mud (in extreme cases 4 tons), and 3 to 3½ tons of molasses.

Filter mud contains about 73 per cent of water, ranging as a rule between 68 per cent and 77 per cent, with extremes somewhat beyond the variations named. Filter press cake has a phosphoric acid content of 1 to 2 per cent, a nitrogen content of 0.2 to 0.5 per cent, and a potash content of as low as 0.05 per cent and as high as 0.27 per cent.

Molasses contains from 15 to 25 per cent of water. It has a potash content that varies from about 2 per cent to over 4½ per cent.

The value of filter mud for agricultural purposes is so firmly established that it is carried in trucks or by rail for miles, and on pack mules for considerable distances to be placed on the field.

The value of molasses is so poorly established that when, as at present, the market for this material is weak, thousands of tons of it are put into the sea.

Filter Mud

The value of this material has been established largely by observing enhanced cane growth where it is applied to the fields.

We lack and need specific measure of the good it does (or fails to do) when applied in different quantities in different ways. The irrigation specialists tell us "The key to water economy is water measurement." Any economic handling of a material or commodity is in fact dependent upon measurement. Just as the sciences of chemistry and engineering have dealt so largely with the art of measurement, so, too, must agriculture apply measurement as far as practicable to all its affairs.

There are several ways of applying press mud to the field and these are presented briefly so that they may be discussed.

In general, there is the tendency to favor the poorer fields or the poorer spots with press mud applications as a means of building them up. There is the practice of placing the mud broadcast on the field ahead of the round plowing. There is the practice of making a surface application to fields under ratoon cropping. There is the custom to put it in a furrow and cover it. There is the method of placing the filter mud in the plant cane furrow, covering it lightly with soil and then placing the seed cane over it.

* Presented at Tenth Annual Meeting of Association of Hawaiian Sugar Technologists, Honolulu, October 19, 1931.

Irrigated plantations often apply press mud in the irrigation water. W. J. Maze, in a bulletin of the Bureau of Labor Saving Devices, described a method of sluicing the press mud upon the fields of an unirrigated plantation by using the ordinary cane flumes. The Hilo Sugar Company uses this method and claims fine results in reaching areas where otherwise it would be too costly to pack the material.

This appears to be a method that deserves special consideration. Some hold that it has the disadvantage of running the filter mud to the low spots where it is not needed, while others claim that if the head of water is low, as it should be, and the flumes are skillfully handled, the filter mud can be placed where it is wanted.

Perhaps the most important point for us to discuss about filter press mud is its relation to commercial fertilizers. Some plantations reduce the applications of mixed fertilizers or nitrogen dressings where the mud has been applied; others do not.

It is possible that unless we take full account of the fertilizing value of filter press mud, and adjust our commercial fertilizers to conform, we may forego the profit we are accustomed to attach to the use of it.

Molasses

We have a considerable amount of evidence that molasses stimulates cane growth on many soils. Frequently the juices are made poorer and no sugar gains result. Here, too, we need to know more about the relationship between molasses and the other fertilizers we apply. J. N. P. Webster has made an interesting review of the results from various field tests at a number of plantations. His paper, quoting the views of several plantation managers, is presented herewith.

The investigations of the Ewa Plantation Company have been furnished us by George F. Renton. A summary of the work, taken from a report by J. L. Nicoll, follows:

1. In general molasses application reduces juice purity. In cases where added cane tonnage overshadows this juice depression net sugar gains are evidenced.

2. Molasses applied before plowing results in appreciable sugar gains on immediate crop harvest. No further ratoon data have as yet been obtained. Unless new methods of application are devised this system is not practical on field scale.

3. Molasses applied in first irrigation on ratoons gives no sugar gain on first crop harvest and tends towards slight loss. Blotched, unhealthy, yellow, and rich green areas appear soon after the cane sprouts and continue until the cane becomes recumbent and further observation is not possible. No ratoon data have yet been obtained.

4. Molasses applied on young growing cane results in leaf burning, particularly in the wet soil type areas. Juices are depressed on both first crop and second crop harvests. There is, however, a slight gain of sugar over the two crops.

5. Molasses applied on mature cane in the last irrigation before harvest produces no effect on the juices of that same crop at harvest. In the following crop

it produces appreciable sugar gains. No burning of leaves takes place except where stagnant water remains in the furrows following irrigation.

6. Injury to cane and yellowing of leaves is believed to be due to excessive available iron and aluminum.

7. Molasses application particularly relieves chlorotic cane.

8. Growth is materially stimulated by molasses.

9. The moisture-holding capacity of a soil is increased through molasses application.

10. It is recommended that field application of molasses be made in the final irrigation before harvest of an area.

11. It is recommended that further and more accurate tests be installed to fully determine benefits derived from molasses application in last irrigation. Until these data have been secured experimentation along other molasses application lines does not seem advisable.

During the early part of the year, Mr. Renton wrote as follows:

> At present we are applying ten tons of molasses per acre in the last irrigation in some of our fields, before harvest on fields which we are now going to plow, and five tons per acre in last irrigation before harvest on those fields which we expect to ratoon.
>
> We anticipate small gains in sugar yields from these applications and possibly some residual effect from this treatment. We are basing these conclusions on the results of experiments. . . .

E. W. Greene, of the Oahu Sugar Company, has been quoted by Mr. Webster in his paper, to which you are referred. We shall not repeat here except to lend emphasis to his statement:

> We doubt whether good results can be obtained where molasses is put continuously into a large ditch and applied more or less indiscriminately over a group of fields.

Other plantations replied to our inquiries during the year along these lines.

Experience on Maui

Maui Agricultural Company, Ltd.:

> We have had no experience in applying molasses in the fields excepting in the irrigation water, or by waste water, when available, to fallow lands.

(See attached report of Mr. Webster for mention of results of cooperative experiments.)

Hawaiian Commercial and Sugar Company, Ltd.:

(See attached report of Mr. Webster for mention of results of cooperative experiments.)

Pioneer Mill Company, Ltd.:

(See attached report of Mr. Webster for mention of results of cooperative experiments.)

Wailuku Sugar Company:

. . . We have not applied molasses to the fields on a large scale, nor have we carried on any tests that would be of interest to the Association.

Kacleku Sugar Company, Ltd.:

We have made no experiments or tests with applications of molasses as a fertilizer which would be of any value to you.

Experience on Kauai

Kilauea Sugar Plantation Company:

As for observations on applying molasses on a large scale to the fields, the writer has, for several years, applied it in the main ditches at Pioneer Mill Company with no apparent ill effects. Small reservoirs were made at convenient points along the ditches, near the railroad track. The molasses was dumped into these reservoirs from the tank cars and fed into the ditch at a rate that gave between two and five tons per acre. These reservoirs are very necessary as it was found that without them there was a tendency, at times, for the molasses to become too concentrated, which would invariably result in a severe burn.

As we have received instructions to waste our molasses we are planning to handle it in the same way here. Small reservoirs are being made adjoining each of two main supply ditches, from which the molasses will be applied to the entire area under these ditches.

We are installing two molasses tests in a field to be planted later on in the year. We find that a convenient, accurate method of applying varying amounts is to irrigate it in the old line prior to harvesting, orient the plots and relocate them in exactly the same place after planting.

The Koloa Sugar Company:

. . . with the exception of the past two years when we sold our molasses, all molasses for the past 30 or 40 years has been applied to a certain set of fields in the irrigation water. No deleterious effect can be noted.

McBryde Sugar Company, Ltd.:

We have practically made very few applications of waste molasses on our fields. Several years ago, we applied ten tons of waste molasses per acre on one of our upper fields before plowing, and the soil analysis showed that there was a small percentage increase in potash in that field.

We are not at present contemplating to apply any waste molasses on any of our fields.

Hawaiian Sugar Company:

No real experiments or tests have been made with molasses applications on this plantation.

During the year 1928, the following amounts of molasses had to be used owing to lack of shipping facilities, and this was the only reason for using molasses as a fertilizer.

	Acres	Tons
Field 1, plant crop, 1930	50	1,340
Field 4, ratoon crop, 1929	15	225
Field 8, ratoon crop, 1929	3	15

This was applied in the irrigation water in each case, and these fields were selected as being convenient for the handling of the tank cars.

We quickly discovered that the application to Field 1 was much too heavy, and the cane was retarded for two or three months. The juices from this part of the field were lower than usual, and also much lower than from the other parts of the field. We figure that no more than 15 tons per acre should be applied in irrigation water.

Since that time we have not used any molasses for fertilizing, but if we should ever have to do so, the only method we would consider is by plowing under by the steam plows.

Kekaha Sugar Company, Ltd.:

So far there has been no experiment along this line here, but plans are being formulated to conduct such an one in the near future.

Experience on Hawaii

Onomea Sugar Company:

Should it become necessary to dispose of our molasses by applying same to our fields, we believe a good plan would be to have a large tank fitted onto an Athay Truss Wagon with creeper tractor wheels and have a tractor handy to pull it into the fields to distribute the molasses and return the wagon to the roads again for a refill. Now, whether the county officials would allow this hauling to be done on the roads or not, we would at least have some tractor or truck with pneumatic tires to haul same on government road.

Even at $5 per ton for molasses, it would be rather expensive to apply 10 tons per acre, counting hauling, etc. This money might be more advantageously spent for other fertilizer ingredients.

Our idea in applying molasses would be to apply it on ratoons where there would be firmer ground for traction and have the molasses piped from tank to each side of row, taking two rows at a time.

This is just a rough outline how it might be handled should it become a regular practice.

Pepeekeo Sugar Company:

. . . regarding molasses we would say that we have not used any as a fertilizer.

Honomu Sugar Company:

We ran two experiments with molascheake and a 10-ton per acre dose showed a gain of almost half a ton of sugar. This was against the regular plantation fertilizer practice. A treatment of 10 tons of molasheake without fertilizer showed a tremendous loss.

We have observed straight molasses application at the rate of 5, 10 and 15 tons per acre on small plots and cane growth seemed to be sitmulated considerably in each case. We have had no experience in applying straight molasses in large quantities to our fields.

We refer you to Experiment 15M and 16M, 1930 crop, for results of molasheake experiments.

Hakalau Plantation Company:

The gains due to molashcake are substantial, although they are obtained at considerable expense.

Laupahoehoe Sugar Company:

. . . to date we have not experimented in that line.

Paauhau Sugar Plantation Company:

We have no experiments or tests to report upon with molasses applications.

We did, however, make up two real sizable piles of molasheake during 1928. Six hundred and sixteen tons of molasses were put into this pile, or approximately one-third, and approximately 30 tons of mill ashes with about 100 tons of bagasse, the balance being mudpress. The analysis from this mixture will be found in your laboratory No. 7595, dated November 17, 1928. Placing a value of 5 cents per pound for K_2O and P_2O_5, and 20 cents per pound for nitrogen, the elements in this tonnage were calculated to have a value of $8,888.40, or approximately $4.85 per ton of molasses. This material cost us for mixing and applying, $2.53 per ton, no charge being made for the molasses used, made up as follows: $1.16 for mixing and $1.37 for applying.

The fields which received an application of between 5 and 10 tons of this mixture, responded well to the treatment, but we cannot say that they responded any more than they would have done with mudpress only.

Union Mill Company:

We have not had any experiments or tests with molasses application. However, for many years up to crop 1930, our waste molasses was applied to our fields in the irrigation water. As far as the writer has been able to observe, this has had very little effect on the cane yield of these fields.

Hutchinson Sugar Plantation Company:

We do not use molasses as a fertilizer on this plantation.

Hawaiian Agricultural Company:

We would say that we have only upon one occasion used molasses in the field. We got no results from these. This is the only time we used molasses as fertilizer, having had to use it formerly as fuel.

Olaa Sugar Company, Ltd.:

It is believed that on the lower lands of Olaa Sugar Company, where the soil is very shallow, rocky and well-drained, and high in organic matter, molasses applications will do most good when applied to the growing crop. The response to such applications can be noted within two weeks or so, without any depressing effect on the crop preceding the time when response can be noted.

When the molasses was applied two months or so ahead of planting on a field scale and in some observational tests, no response could be noted to these applications.

Heavy applications have been tried in observational tests wherein the molasses was put on the stubble of ratoons with remarkable response, and no ill effect on the cane.

Molasses will stimulate honohono, and on a plantation like Olaa, where this weed is such a problem, stimulants of this sort increase our costs.

Although we believe there is some gain from molasses applications we believe also that the cost of getting equipment sufficient to handle all of our output would be prohibitive at present, at least with us.

Waiakea Mill Company:

No such practice has taken place on this plantation, so we are unable to give you any information relative to this operation.

Experience Abroad

In a letter to E. W. Greene, dated April 14, 1931, John Murray, of Durban, South Africa, contributed the following information on the subject of molasses:

So as to obtain knowledge of the use of molasses, as a fertilizer, I wrote to various men who manage large estates here, and I herewith give their views:

William A. Campbell, managing director, Natal Estates, Limited, Mount Edgecombe, Natal, says:

"We thank you for your letter of the 30th of March, and in reply have to advise you that we have applied molasses as a fertilizer for over 50 years on the estate. There is a certain amount of trouble in getting equal distribution of the molasses on the fields. Our method is to take it out in tanks on wheels especially built for our tramline. The molasses is then run in furrows such as one would irrigate water, and applied to the field at least a month before planting. Taking, for instance, our poor sandy soil which has been completely worked out, and on which no fertilizer seems to be of any use, treacle applied to this type of soil has given phenomenal yields to over 50 tons of cane per acre, where fertilizers have been a complete failure. We find that treacle binds the sandy soil, attracts moisture, and benefits the soil for years to come. A friend of the writer's, Mr. Ebbels, of Mauritius, discovered that treacle had a power of increasing the nitrifying bacterial action (Azota). All fields treated with treacle are wonderfully green in color. Treacle applied on stiff clay lands as compared to sandy soil is a totally different proposition. On stiff clay lands, unless the field is treated a year before planting, it is apt to kill the cane, in that water collects in little hollows, etc., whereas on sandy soil the reverse takes place. The manurial value of our molasses is chiefly in its potash, 4.5 per cent to 5 per cent with a small amount of nitrogen .3 per cent, although the sugars and organic matter can also be reckoned to be stimulants of some value. We set a value on our molasses for one penny to 1½ pennies per gallon for manure purposes. Next to scum cake (double carbonatation) we consider treacle away ahead of any fertilizers. We also find that molasses remains available in the soil over a long period. We do not prepare the soil as a rule with limestone."

Mount Edgecombe Factory turns out approximately 40,000 tons of white sugar per annum, on the double carbonatation system, using about 5 tons of limestone for every 100 tons of cane crushed, so naturally their press cake is valuable. The limestone is good, viz., 97.5 per cent C. a. C.O. 3, .5 per cent iron alumina, .5 per cent magnesian carbonate, 1.5 per cent silica.

Mr. Edward Saunders, the managing director of the Tongaat Sugar Company, Limited, a concern turning out some 45,000 tons of raw sugar per season, says:

"The question of burning molasses is one which I went into very fully some years ago, and I found that there was no practical difficulty in doing so. The only objection to molasses as a fuel was the tendency to form a thick coating on the boiler tubes, otherwise they burnt quite freely.

"On the other side of the question, i. e., their value as a fertilizer, about this there is no question whatever, assuming the actual value delivered on the ground at approximately (1 pound) per ton, purely for their fertilizer contents. One of the difficulties of utilizing them this way is that it becomes very costly to do so, unless you have a system of irrigation and they can be mixed with the water in the furrows, so great is the difficulty of applying them without these facilities that to all intents and purposes it becomes a non-paying process. In the meantime, however, we have no difficulty in disposing of our molasses locally and so long as it is possible to do so, it suits our purpose better than to attempt to use them as a fuel, as bagasse supplies all that is necessary for this purpose."

Mr. H. H. Dodds, the director of the Sugar Experiment Station here, states:

"The Hawaiian people are fortunate in being able to sell their molasses in its original condition from the factory at a satisfactory price, which is apparently by no means the case here. In view of the vast amount of scientific and experimental work in

agriculture of sugar cane that has been carried out in Hawaii for many years and has made them one of the leading countries of the world in such matters, it is rather surprising that they have only discovered since 1922 the value of molasses in the soil. One would have supposed that it would have been more profitable to utilize the valuable fermentable carbohydrate of the molasses and apply the fertilizer elements in the form of dunder after fermentation and distillation had been completed, but it is conceivable of course that alcoholic fermentation may in some way be a benefit to the soil preparatory to planting crops. Most of the sugar soils in this country are more or less acid, ranging from 5.0 to 6.0 pH, but this does not appear to be a serious obstacle to the use of molasses as a fertilizer. We have not been able yet to get round to any fertilizer experiments with molasses at this Station, but hope to be able to do so before long. It is evident that the biological activity of the soil should be studied during the course of such experiments, but without any biochemist on the staff we have not much prospect of being able to do this. I will write you further on this subject.''

Natal is a very hilly country and the transport of the molasses would appear to be a great obstacle to its use as a fertilizer. Could you help in any way to suggest a means of getting it on the fields cheaply?

MOLASSES

By J. N. P. Webster

In the June 10 issue of a memorandum of the agricultural department of the Experiment Station, mention was made of the increased interest in molasses at present, due to its low sale value and the possibility of profitably applying it to fields.

E. W. Greene, manager of Oahu Sugar Company, Ltd., has favored us with his views on the use of molasses applications and we quote from his letter the following:

> We have found that under our conditions 10 to 20 tons of molasses an acre applied before plowing give excellent results. Thirty tons seem to be more than neecssary. The best application for ratoons under our conditions is from 3 to 5 tons an acre. More than 5 tons an acre are apt to burn the cane and retard growth. No retardation of growth occurs with us with 3 tons or less in ratoons and the beneficial effect is soon apparent.
>
> Probably the desirable amounts to apply will vary with different conditions on different plantations.
>
> We have found it advisable, in putting molasses on ratoons, to apply a definite amount to one field in one round of irrigation. We doubt whether good results can be obtained where molasses is put continuously into a large ditch and applied more or less indiscriminately over a group of fields.
>
> We believe that there is a long-continued benefit from the application of molasses to fields.

During 1930, a number of experiments were harvested which showed gains in cane tonnage from molasses applications, but in every case there was also an increase in quality ratio, which, unless there was a considerable gain in cane, would tend to offset any benefit from the molasses.

At Olaa Sugar Company gains were experienced in an experiment where molasses was applied up to 15 tons per acre. However, this same experiment in the following crop showed no response from the residual effect of the molasses.

Regarding Experiment F at Waipio, F. C. Denison states:

> Ten tons per acre molasses was applied to the 1928 crop in the last irrigation before harvesting.

This application did not affect the 1928 crop, but favorable results were found in the following crop.

In an observation test at Waianae, there were indications of substantial gains of both cane and sugar.

At Pioneer Mill Company, an experiment in which molasses was applied at the rate of 10, 20, 30 and 40 tons per acre shortly after harvest and before plowing, showed gains in sugar in the plant crop up to 30 tons of molasses per acre, while the residual effect in the succeeding crop was found beneficial up to 40 tons of molasses per acre.

In another experiment at Pioneer Mill Company, where 10 tons of molasses per acre were applied in the irrigation water at the start of the crop, H. J. W. Taylor comments:

> The two level ditches having received molasses, show up to distinct advantage in every way.

Two observation tests, one at Olowalu Company and the other at Maui Agricultural Company, gave good gains in cane and sugar from applications of about 20 tons of molasses per acre.

At Kilauea, gains in cane and sugar from applications of 10 and 15 tons of molasses were experienced in an experiment, while the application of 5 tons seemed to have a depressing effect.

An observation test recently harvested at Waialua Agricultural Company where applications of 3, 6 and 12 tons of molasses per acre were applied, primarily to determine the relation of brown stripe disease, showed increases in cane and sugar from each of the applications.

In the early part of this year data were requested from the managers of the various plantations in regard to their experience with the use of molasses as a fertilizer, and the following excerpts are made from their replies:

George F. Renton, manager of Ewa Plantation Company, states:

> You will note that here at Ewa we find a detrimental effect on juice purities quite consistent, but, on the other hand, cane yields show a noticeable gain.

At Hawaiian Commercial and Sugar Company for the 1929 crop, three test areas were given applications of molasses to determine the reaction. Previous to plowing and planting two of the areas received 30 tons of molasses per acre. At harvest one area showed no gains while the other showed a gain of 24 tons of cane and 2.8 tons of sugar per acre. The third area, in first ratoons, was given an application of 24 tons of molasses per acre in 1927, and at harvest the gain was 12 tons of cane and 1.5 tons of sugar per acre.

F. F. Baldwin states:

It is realized that no great weight can be given to the above figures since they are from but single level ditch plots. They do substantiate, however, growth observations made during the progress of the crop. In the one case where no yield response was found at harvest, no differences were seen during the growth of the cane.

For the 1930 crop, Mr. Baldwin continues:

Four hundred and forty-six acres received molasses at an average of 31.2 tons per acre previous to plowing and planting, and 124 acres of first ratoons received molasses at 15.5 tons per acre. With one exception, the fields included in this acreage produced good cane yields compared to their past records. The quality of the juice was not up to past records, however, so that sugar yields were somewhat disappointing. . . .

Two small check areas in this same crop showed gains in cane and sugar from applications of 28 and 32 tons of molasses per acre.

1931 Crop—5,075 tons of molasses were applied to 175 acres that were plowed and planted. None of this area has been harvested to date. Observations on a check layout consisting of four treated level ditches against four alternate untreated level ditches would indicate that considerable more cane is to be expected from the treated area (possibly 20 tons). Juice samples indicate that there is good juice quality in untreated plots at this time as compared to treated plots. The field is being left for later harvest with the hope of reducing the tons cane per ton sugar to a minimum.

Commenting on an experiment at Olaa Sugar Company, where molasses was used with mudpress, Raymond K. Conant, research agriculturist, states:

It is interesting to note that with the exception of the 10-ton molasses plots, molasses and mudpress alone gave handsome gains over mudpress and commercial fertilizer.

Molasses, mudpress and commercial fertilizers gave consistent gains over mudpress and commercial fertilizer. Generally speaking, these gains were no greater than those shown by the molasses plots without commercial fertilizer. The 10-ton molasses plots are the exception again.

The experiment indicates that molasses at the rate of 15 tons per acre when applied in the interlines at the very start of the crop in combination with 12 tons of mudpress per acre applied early, gives better yields than mudpress and commercial fertilizer.

At Onomea Sugar Company, applications of 10 and 20 tons of molasses were applied to second ratoons of Yellow Caledonia for the 1929 crop, in a small experiment. The results showed gains for the molasses applications in cane and sugar and when this was again harvested for the residual effect in the 1931 crop the gains were still apparent.

Commenting upon the use of molasses at Pioneer Mill Company, C. E. S. Burns, manager, states:

Our first experiments with molasses as a fertilizer were of the observation type. In B-4 Field a very heavy application of molasses was made before the field was plowed. This was estimated at 100 tons per acre. There was very little, if any, response to this treatment in the plant crop (1924), but every ratoon crop since then on the area which received the molasses has greatly outyielded the rest of the field. In Field L-2, which was planted in 1923, we had a molasses and mudpress test. This field is split in half by a straight ditch, one side of which received a very heavy dose of molasses (75-100 tons

per acre) and the other side a heavy dose of mudpress. These applications were made about a year prior to planting. Both treatments gave much heavier yields of cane than the field had ever produced before. . . .

Several plantations have used molasses in combination with mudpress and bagasse, while a good many have never used molasses at all.

From what data we have and with a number of instances where gains have been shown from molasses applications, we might more profitably apply molasses to a greater acreage. Of course, it must be realized that the cost of applying molasses becomes a limiting factor where it has to be hauled to fields by means of tank trucks and then distributed, and this applies particularly to unirrigated plantations. On irrigated plantations the distribution of molasses is not such a factor as the common procedure is to apply it to fields in the irrigation water.

The amount of molasses to apply to a plant or ratoon crop is more or less an open question and the profitable limit will have to be determined experimentally. Applications of 10 to 20 tons of molasses per acre applied to a field previous to plowing and planting is perhaps a fair amount until more is known. The incorporation of molasses in the soil in this manner is probably most satisfactory as the decomposition processes will have advanced considerably before a field is ready to plant. It is well known that seed pieces when germinating in contact with molasses will suffer. For ratoon crops an application of about 3 to 5 tons per acre applied to the side of the stubble or in the irrigation water is perhaps sufficient.

Where molasses is applied it appears that greater attention should be paid to the amount of nitrogen, from commercial fertilizers, which a field is to receive. The complaint most often encountered from applications of molasses is that the juices become poorer, thus offsetting to some extent the gain in tonnage. It is a known fact that to keep the biological activities of the soil in equilibrium a certain amount of nitrogen along with the molasses is necessary. Otherwise the organisms, whose duty it is to decompose the molasses, draw upon the nitrogen of the soil for their life processes and the plants suffer. Thus, if molasses is applied at intervals to a growing crop, without attention being paid to nitrogen requirements, then there will be periods of depressed growth and of good growth noticeable in a crop. The depressed growth is due to the organisms utilizing the nitrogen in the soil and later when they have no further material to feed upon they die and the nitrogen stored up in their bodies becomes available to the plants. The activity of the organisms is also dependent upon weather conditions and thus it can be seen that the nitrogen from their bodies may be available to the plants over a long period of time in unfavorable weather and a short period in favorable weather.

This would indicate that all the molasses should be put on in one early application and not applied at several intervals. Thus if molasses has been applied, say in the irrigation water, to a crop up until it is several months old, there may be conditions such that the nitrogen from the soil organisms will be available to the crop about the time it should normally be ripening off and poor juices will be the result.

It may be that the early application of nitrogen to molasses-treated fields leaving out the spring application, or else reducing this application, will help to improve juices. Or perhaps another method would be to leave out the late summer application of nitrogen in the first year. In practically all the experiments harvested the number and time of application of fertilizer and time of application to treated and untreated plots have been identical. Might this not be a fallacy? What would the differences in yields have been had the time element of the nitrogen applications been taken into consideration in these experiments?

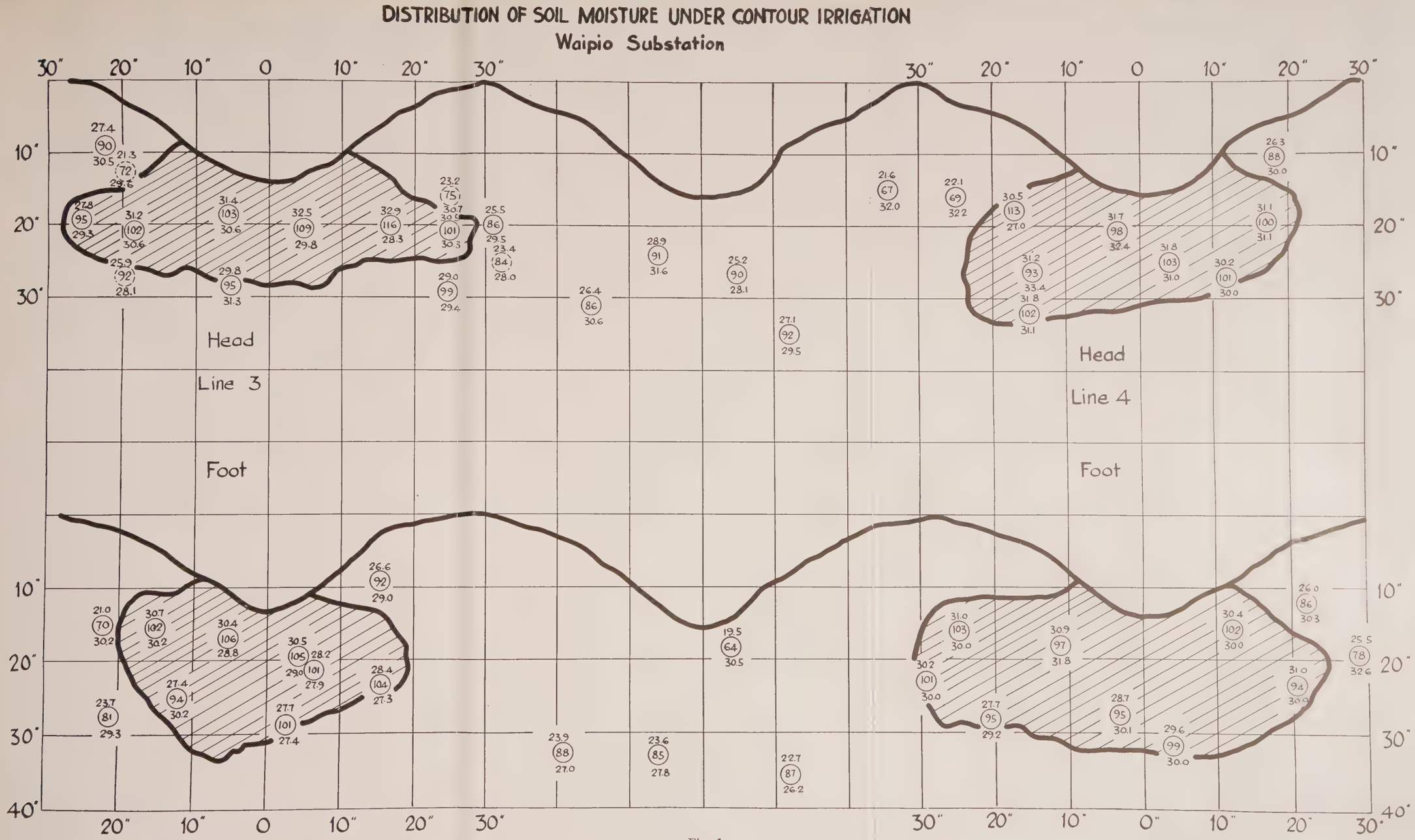

Fig. 1

DISTRIBUTION OF SOIL MOISTURE UNDER CONTOUR IRRIGATION

Waipio Substation

Circles represent position of soil moisture samples.
Dotted circles represent position of samples for capillary movement.
Figure above circle—total percentage soil moisture.
Figure below circle—average of duplicate Moisture Equivalent determinations.
Figure in circle—"Relative Wetness" or Total Moisture × 100 ÷ Moisture Equivalent.
Irrigation Application of 1.34 Acre Inches per Acre.

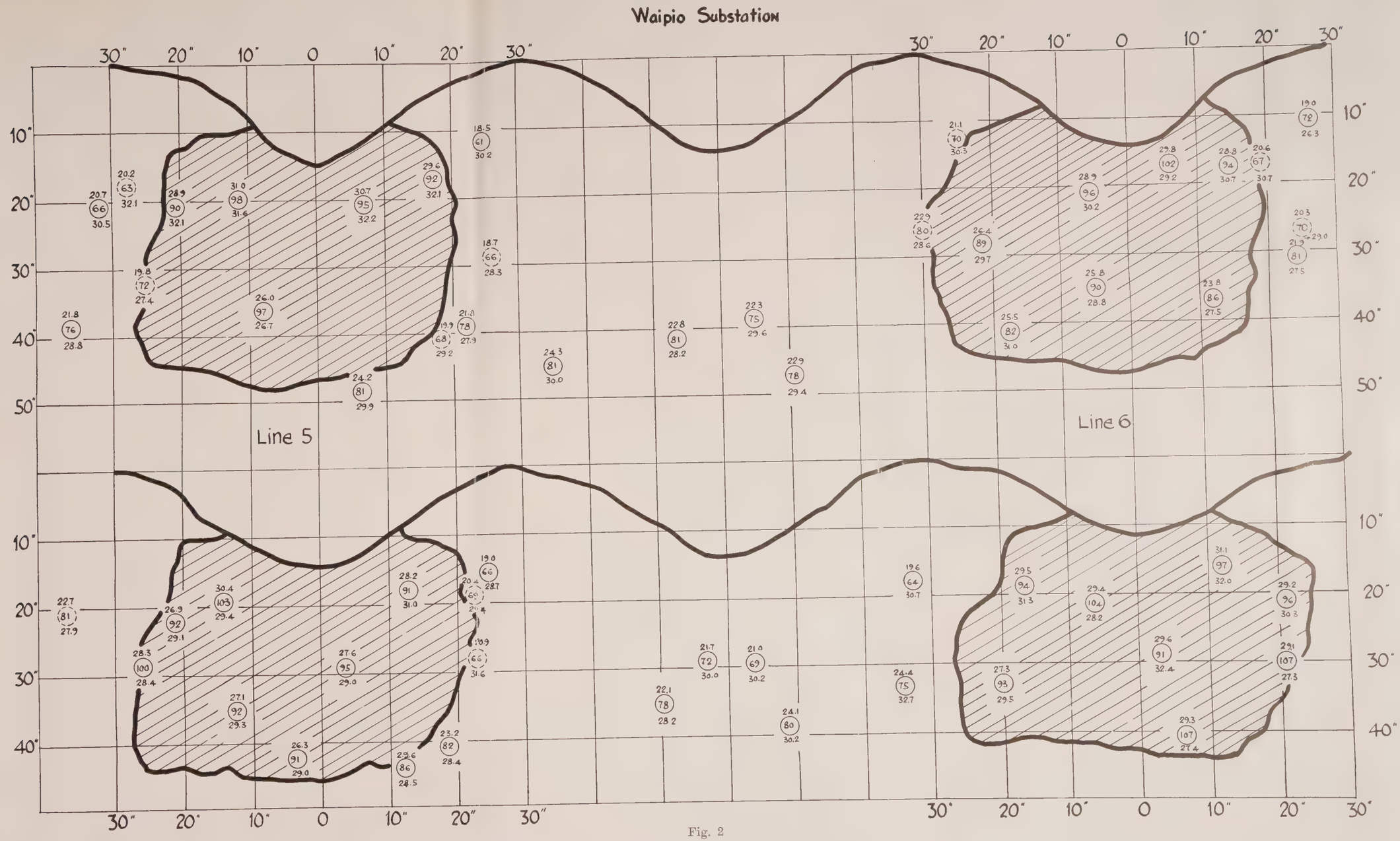

Fig. 2

DISTRIBUTION OF SOIL MOISTURE UNDER CONTOUR IRRIGATION

Waipio Substation

Circles represent position of soil moisture samples.
Dotted circles represent position of samples for capillary movement.
Figure above circle—total percentage soil moisture.
Figure below circle—average of duplicate Moisture Equivalent determinations.
Figure in circle—"Relative Wetness" or Total Moisture × 100 ÷ Moisture Equivalent.
Irrigation Application of 2.00 Acre Inches per Acre.

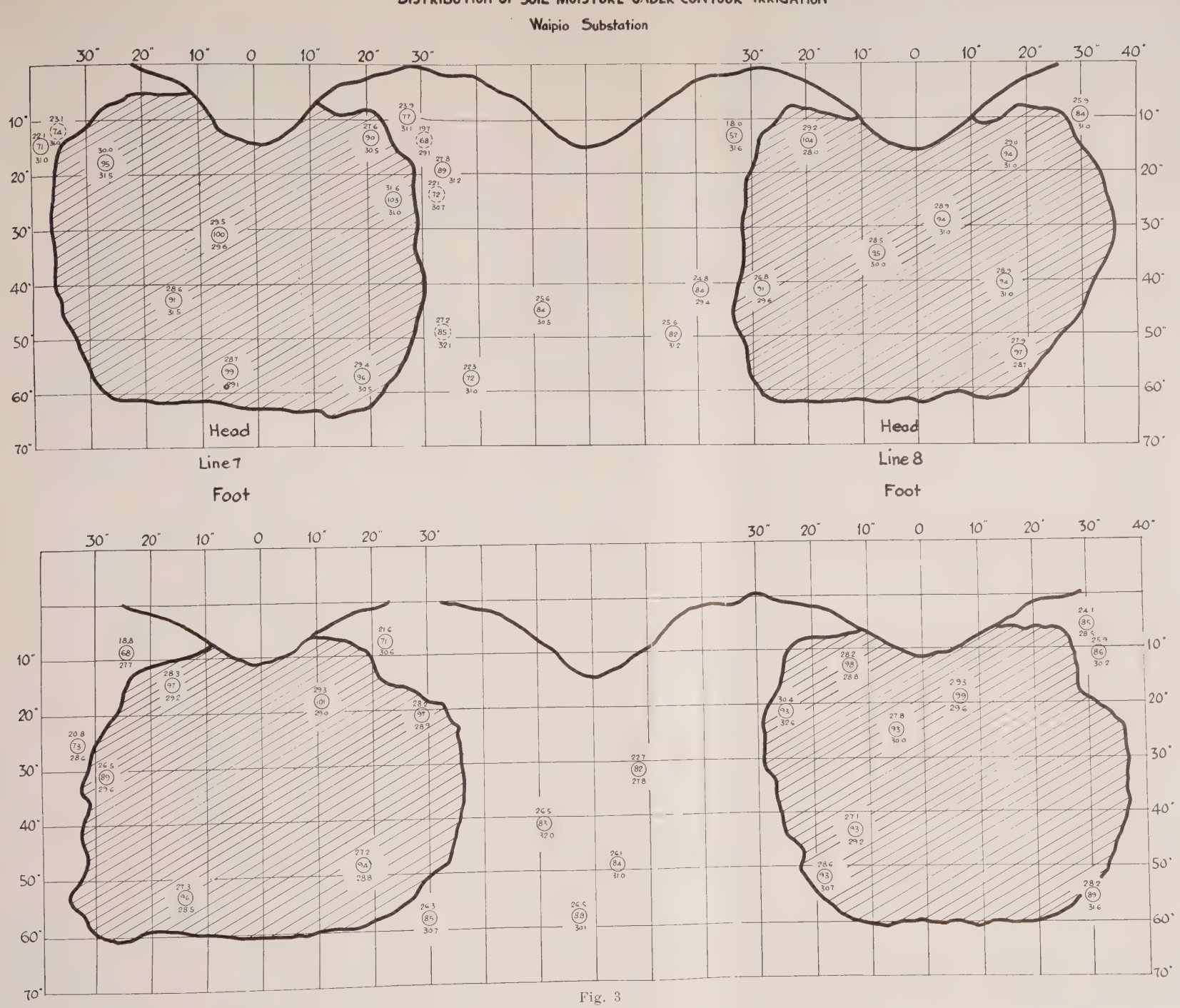

Fig. 3

DISTRIBUTION OF SOIL MOISTURE UNDER CONTOUR IRRIGATION

Waipio Substation

Circles represent position of soil moisture samples.
Dotted circles represent position of samples for capillary movement.
Figure above circle—total percentage soil moisture.
Figure below circle—average of duplicate Moisture Equivalent determinations.
Figure in circle—"Relative Wetness" or Total Moisture × 100 ÷ Moisture Equivalent.
Irrigation Application of 4.00 Acre Inches per Acre.

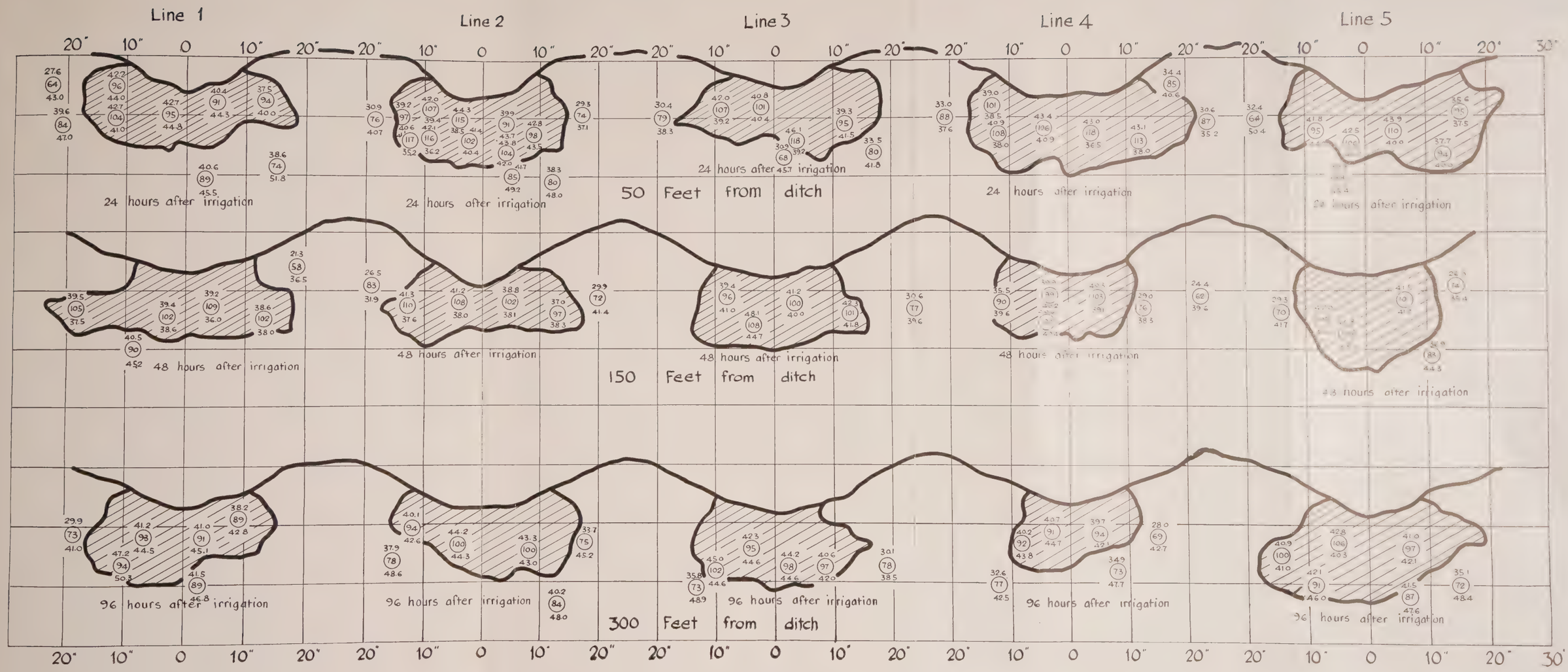

Fig. 4

DISTRIBUTION OF SOIL MOISTURE UNDER LONG LINE IRRIGATION

Waimanalo Sugar Company—Field 11

Circles represent position of soil moisture samples.
Figure above circle—total percentage soil moisture.
Figure below circle—average of duplicate Moisture Equivalent determinations.
Figure in circle—"Relative Wetness" or Total Moisture × 100 ÷ Moisture Equivalent.

DISTRIBUTION OF SOIL MOISTURE UNDER LONG LINE IRRIGATION
Waimanalo Sugar Co. Field 11

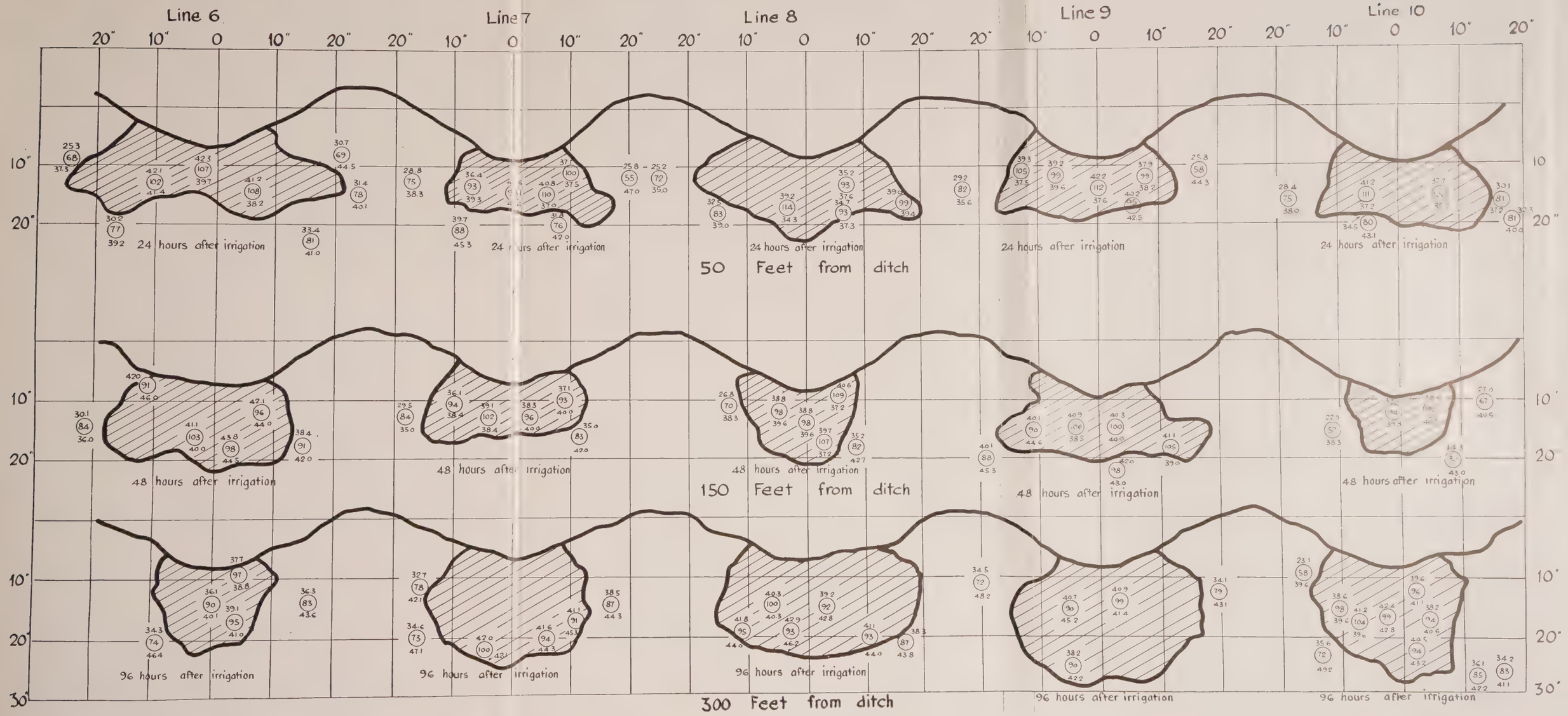

Fig. 5

DISTRIBUTION OF SOIL MOISTURE UNDER LONG LINE IRRIGATION

Waimanalo Sugar Company—Field 11

Circles represent position of soil moisture samples.
Figure above circle—total percentage soil moisture.
Figure below circle—average of duplicate Moisture Equivalent determinations.
Figure in circle—"Relative Wetness" or Total Moisture × 100 ÷ Moisture Equivalent.

The Distribution of Soil Moisture After Irrigation

By H. R. Shaw

Introduction

The manner and extent of soil moisture distribution after irrigation is of immediate and vital concern in the production of sugar cane from approximately 120,000 acres in the Hawaiian Islands. Large areas of cultivated land are entirely dependent upon artificial applications of water by irrigation during the greater part of the year. The recent extensive development of methods of irrigation designed to increase the efficiency of labor and of water application makes the distribution of soil moisture of even greater immediate importance. In the last analysis the success or failure of any system of irrigation lies in its ability to provide and to maintain a proper distribution of moisture to the root system of the plant.

Investigations in England and the United States (1, 2, 3, 4) indicate that the moisture-holding properties of a soil are intimately connected with the physical texture, and particularly with the colloidal fraction, of the soil type. Recent studies in Hawaii (5, 6, 7) point to the fact that there may be a wide range in the moisture-retaining characteristics of soils within rather restricted areas. Moreover, the soil texture appears to govern not only the amount of moisture which may be held by the soil immediately after irrigation, but also the amount of moisture retained in the soil at the time plant growth is retarded because of an inadequate supply of available water. Hence, it would appear that a knowledge of the total percentage of moisture in a soil at a given time is of little value unless the moisture-holding properties of the soil are also known. The moisture equivalent (8, 9) has been found to be a simple and relatively reliable method of determining the moisture properties of a soil. Veihmeyer, Conrad and Hendrickson (10, 11), in California, have found the ratio between total moisture content and moisture equivalent a useful criterion for determining the distribution of moisture after irrigation. This ratio they have termed the "Relative Wetness" of the soil.

Early studies of moisture distribution in Hawaiian soils by Allen (12, 13, 14) at the Waipio substation indicate that "it is impossible to store in the upper 6 feet of (Waipio) soil more than 4½ inches of water of which, on an average, about 2½ inches are retained by the surface 2 feet of soil; the remainder, some 2 acre inches, being held in the lower 4 feet." Allen also found that practically the same amount of water was retained in the soil regardless of the amount of irrigation water applied, and that 65 per cent of a 9-inch irrigation and 47 per cent of a 6-inch irrigation passes below 6 feet and is lost to the plant.

Laboratory Studies on the Distribution of Moisture in Small Containers

Attempts frequently have been made in soil moisture and physiological investigations to study plant growth in soils purportedly maintained at definite and pre-

determined moisture contents. Thus one encounters references in the literature to comparative studies of plants grown in pot cultures which were "kept at moisture contents of 10, 20 and 30 per cent" or similar ranges of soil moisture. The highest yield of plant material from a pot series of this type is generally inferred to be the soil moisture content most satisfactory for plant growth in the soil type and with the plant species under investigation. The desired soil moisture content is generally obtained by determining the oven-dry weight of the soil in the culture, and by adding to the surface of the soil the quantity or weight of water necessary to bring the mass to the calculated moisture content. In other cases the dry soil and calculated amount of water are mixed thoroughly before being placed in the pot, and the amount of water lost through plant transpiration is added daily to the soil surface so that the same gross weight may be maintained constantly.

Studies at the Waipio substation indicate that although it is possible, with sufficient care and precaution, to prepare a small sample of soil at a predetermined moisture content, it is impossible to attain this objective by adding water to the surface of the soil. It is equally impossible to maintain this moisture content by adding water to the soil surface after moisture at the lower depths has been depleted by plant root action.

Cardboard cylinders (ice-cream cartons) about 4 inches in diameter and 8 inches deep were used in the studies reported here. The interior of each cylinder was coated with paraffine to prevent seepage or evaporation of water. Sifted Waipio soil was oven-dried at 110° C. for 48 hours, after which a definite quantity (1500 grams) was weighed into a container. The weight of water necessary to bring the soil to the desired percentage of moisture was added according to the various methods described below, and the moist soil packed immediately into the cardboard cartons. The cartons were covered and placed in a dark, humid atmosphere for 48 hours in order that the soil and water might come into approximate equilibrium.

The carton was then cut into one-inch increments with a sharp knife, and the soil material from each successive increment was divided into two samples, which were placed in soil moisture tins, weighed, and dried in an electric oven at 110° C. for 48 hours. It was thus possible to determine with a fair degree of accuracy the distribution of moisture throughout the soil mass as well as any departures from the desired soil moisture content.

1. *Water Added to Surface of the Soil:* It was desired to bring the dry soil to uniform moisture contents of 10, 20, 25, 30 and 40 per cent based on the oven-dry weight of soil. With samples of 1500 grams of oven-dry soil, additions of 150, 300, 375, 450 and 600 grams of water to the respective containers were necessary. The oven-dry soil was weighed into the carton and packed as uniformly as possible. The calculated weight of water was added through a 50 cc. pipette to the surface of the soil.

The results of the soil moisture percentages of each sample are shown as follows:

	Carton No. 1		Carton No. 2		Carton No. 3		Carton No. 4		Carton No. 5	
1″	27.5	27.3	31.0	30.7	32.5	32.7	25.9	34.9	38.3	38.1
2″	26.3	25.9	30.8	30.5	32.4	32.8	35.5	33.5	37.6	38.2
3″	17.7	15.1	30.2	30.0	32.6	33.1	33.6	33.8	39.2	39.3
4″	3.7	2.4	27.6	28.1	31.8	31.0	33.4	32.6	42.8	38.8
5″	0.8	0.8	12.9	11.0	27.7	24.5	31.4	28.9	39.7	38.9
6″	0.9	1.1	2.5	2.8	11.2	7.9	24.0	15.5	37.6	37.1
7″	0.0	0.1	1.0	1.5	3.7	5.0	11.1	6.1	35.9	35.1
	"10 Pct."		"20 Pct."		"25 Pct.		"30 Pct."		"40 Pct."	

It is obvious that the distribution of moisture throughout the soil mass when a predetermined weight of water is added to the surface is far from adequate. Apparently a given soil has the capacity of holding around its granular or colloidal structure a certain quantity of water. When the surface increment of dry soil has satisfied its capacity for moisture, water flows by gravity to the next lower soil increment where sufficient moisture is adsorbed to satisfy the capacity of the second increment. This sequence is continued until all of the water is held by the soil. The soil at the lower depths apparently receives little if any water until the adsorbing power of the upper increments has been satisfied.

Hence, when 150 grams of water were added to the soil in Carton No. 1, the supply was apparently great enough to satisfy the water-holding capacity of the first 2 inches and part of the third, while soil at the lower depths increased its moisture content by an insignificant amount. When 300 grams of water were added to the soil in Carton No. 2, the supply was sufficient to satisfy the soil in the first 4 inches and part of the 5th, etc.

The variation in moisture content in the wetted area of the upper horizon may be attributed to uneven penetration of water through the soil packed in small containers. Some of the water undoubtedly followed the walls of the container and thus increased the moisture content of small areas at the lower depths.

The distribution of soil and water throughout the soil mass is shown in the following table. The total amount of dry soil and of water in each increment of depth after sampling is shown in the first two columns. In general, the total weight of dry soil recovered in sampling is very close to the calculated amount although it was impossible to remove every gram of soil from the container in the process of sampling. In the first three cases where small amounts of water were added, the total weight of water recovered is sometimes slightly higher than that calculated. This may be due to the adsorption of water from the atmosphere (hygroscopic moisture) during handling, or to the fact that the soil may not have been completely dried before packing in the container. Whatever the cause of this gain, it is so slight as to be considered insignificant as far as the results of the study are concerned. In the last two cases in which relatively large amounts of water were added, the amount of water actually recovered is less than that calculated. The loss may be attributed partially to the fact that it was impossible to recover all of the soil and water during sampling, and partially to the fact that some water not held in equilibrium with the soil may have leaked fom the container in spite of the precautions taken.

In the third column is given the average per cent moisture of each one-inch increment as obtained by dividing the weight of water recovered by the weight

of oven-dry soil, and multiplying the quotient by 100. In the fourth column is given the volume weight, an indication of the uniformity of packing. This figure is obtained by dividing the weight of oven-dry soil in each increment into the weight of water which would be contained in a volume one inch deep and with an area equal to that of the carton. It will be noted that there is considerable variation in this figure between successive increments due to the difficulty of packing dry soil uniformly. This variation is largely eliminated in studies reported later in this paper in which the soil was moistened before packing.

The last column gives the ratio of the moisture equivalent of a composite sample of the sifted Waipio soil used in this study to the moisture content of each one-inch increment of soil in the container. The moisture equivalent seems to have a rather consistent relationship to the maximum field capacity of a soil. From studies on 28 Hawaiian soils (6) it appears that the maximum field capacity divided by the moisture equivalent gives a factor of approximately 1.1. Hence if the ratio between the moisture content of each one-inch soil increment and the moisture equivalent of that soil approaches the constant 1.1, it is safe to assume that the soil increment in question is close to its maximum field capacity and that the water-adsorbing power of the soil has been satisfied.

In the studies reported here it is apparent that the moisture content of the soil in the upper horizon is essentially at its maximum field capacity. The transition between moist soil and the dry soil of the lower horizon is rather sharp. In the case of Carton No. 5, to which sufficient water was added to bring the soil to a moisture content of 40 per cent, the ratio of moisture equivalent to moisture content is greater than 1.1 throughout the soil mass. This indicates that the soil was at a moisture content greater than its maximum field capacity. This contention is supported by determinations of the value of the maximum field capacity of Waipio soil. The average of over 100 determinations of this value at Waipio is 34.5 per cent.

Based on the results of this experiment, it would appear that each increment of dry soil must be wetted to its maximum field capacity before the next lower increment may receive any significant amount of water. It would follow that it is impossible to bring a soil mass to a uniform moisture content less than its maximum field capacity by adding water to the surface of the soil.

TABLE I

Distribution of Soil and Moisture after Various Amounts of Water had been Added at the Soil Surface

Depth in Inches	Weight of Oven-dry Soil	Weight of Water	Per Cent Moisture	Volume Weight	"Relative Wetness" Pct. Moisture ×100÷ M. E. (28.9%)
Carton No. 1—150 grams water added to 1500 grams dry soil					
1	154.2	42.2	27.4	0.66	95
2	244.6	63.7	26.0	1.05	90
3	248.7	40.7	16.4	1.07	57
4	277.1	8.6	3.1	1.19	11
5	244.7	1.9	0.77	1.06	03
6	222.5	2.1	0.94	0.97	03
7	101.2	0.3	0.30	0.43	01
Total	1493.0	159.5	10.7		
Calculated	1500.0	150.0	10.0		
Difference	—7.0	+9.5	+0.7		

Carton No. 2—300 grams water added to 1500 grams dry soil

Depth in Inches	Weight of Oven-dry Soil	Weight of Water	Per Cent Moisture	Volume Weight	"Relative Wetness" Pct. Moisture ×100÷ M. E. (28.9%)
1	208.2	64.2	30.8	0.89	107
2	211.3	64.6	30.6	0.91	106
3	231.4	69.6	30.1	0.99	104
4	234.0	65.1	27.8	1.01	96
5	293.9	34.9	11.9	1.26	41
6	213.5	5.5	2.6	0.92	09
7	104.2	1.2	1.2	0.45	05
Total	1496.5	305.1	20.4		
Calculated	1500.0	300.0	20.0		
Difference	—3.5	+5.1	+0.4		

Carton No. 3—375 grams water added to 1500 grams dry soil

1	211.9	69.0	32.6	0.91	113
2	219.8	71.6	32.6	0.94	113
3	227.5	74.7	32.8	0.98	113
4	259.0	81.1	31.3	1.11	108
5	222.5	57.8	26.0	0.96	90
6	254.7	24.4	9.6	1.09	33
7	90.4	3.7	4.1	0.39	14
Total	1485.8	382.3	25.7		
Calculated	1500.0	375.0	25.0		
Difference	—14.2	+7.3	+0.7		

Carton No. 4—450 grams water added to 1500 grams dry soil

1	200.4	61.3	30.6	0.86	106
2	213.5	73.5	34.4	0.92	119
3	263.3	88.6	33.6	1.13	116
4	244.1	80.4	32.9	1.05	114
5	232.9	70.0	30.1	1.00	104
6	216.6	42.8	19.8	0.93	67
7	119.0	11.0	9.2	1.51	32
Total	1489.8	427.6	28.7		
Calculated	1500.0	450.0	30.0		
Difference	—10.2	—22.4	—2.3		

Carton No. 5—600 grams water added to 1500 grams dry soil

1	195.6	74.6	38.1	0.84	132
2	197.7	74.9	37.9	0.85	131
3	220.9	86.7	39.2	0.95	135
4	249.2	97.5	39.1	1.07	135
5	234.3	91.9	39.2	1.01	135
6	218.2	81.4	37.3	0.94	129
7	168.4	59.8	35.5	0.72	123
Total	1484.3	566.8	38.2		
Calculated	1500.0	600.0	40.0		
Difference	—15.7	—33.2	—1.8		

2. *Water Mixed with Dry Soil:* Although it appears from the results of the preceding study that it is impossible to bring a soil to a uniform predetermined moisture content by adding water at the soil surface, attempts were made to attain such uniformity of moisture distribution by mixing the dry soil and water before placing the soil mass in the container.

The sifted Waipio soil was dried at 110° C. in an electric oven for 48 hours, and 1500 grams of the oven-dried soil were spread on a section of oilcloth. The calculated weight of water necessary to bring the soil mass to a certain moisture content was added through a 50 cc. pipette. The soil and water were mixed thoroughly by hand for at least five minutes. Care was taken to break up small lumps of soil and water which formed very readily. After soil and water were felt to be thoroughly mixed, the mass was placed in the cardboard container and allowed to stand for 48 hours in a humid atmosphere in order that soil and water might reach approximate equilibrium. One-inch increments of soil were then sampled in the same manner as that described in the preceding study.

The danger of having the soil adsorb hygroscopic moisture was increased by this method since the soil was exposed to the air for a longer period, during which it was constantly turned and new granular surfaces were constantly exposed. The difficulty of recovering all of the soil and water was likewise increased since the soil, which became very sticky when the larger amounts of water were added, had to be removed from the oilcloth surface as well as from the walls of the container.

In general, however, the distribution of moisture throughout the soil mass was rather uniform, and may be considered adequate for certain studies which must be conducted at fairly uniform soil moisture contents. The distribution of soil and water is shown in Table II.

TABLE II

Distribution of Soil and Moisture after Various Amounts of Water had been Mixed with Dry Soil

	Carton No. 1		Carton No. 2		Carton No. 3		Carton No. 4		Carton No. 5	
1″			18.8	21.0	23.3	24.9	31.0	31.5	38.6	39.0
2″	10.4	10.2	20.4	20.5	24.7	25.2	30.9	31.4	39.7	39.2
3″	9.9	9.5	20.0	20.0	24.7	25.5	30.4	31.7	41.7	40.6
4″	10.8	10.7	21.1	21.0	25.2	25.7	31.3	30.8	41.1	40.6
5″	10.7	10.7	20.6	21.2	26.1	25.7	32.0	25.1	41.7	41.8
6″	11.2	11.0	20.5	20.9	25.5	25.4	31.2	31.4	42.3	41.3
7″	11.5	11.1	20.4	20.5	26.3	25.4	32.0	31.3	42.0	41.9
8″	10.6	10.9	20.9	20.2	27.0	26.2	32.1	31.9	42.3	42.3
	"10 Pct."		"20 Pct."		"25 Pct."		"30 Pct."		"40 Pct."	

Distribution of Soil and Moisture after Various Amounts of Water had been Mixed with Dry Soil

Depth in Inches	Weight of Oven-dry Soil	Weight of Water	Per Cent Moisture	Volume Weight
Carton No. 1—150 grams water mixed with 1500 grams dry soil				
1				
2	113.2	11.6	10.2	1.0
3	228.1	22.2	9.7	1.0

TABLE II—Continued

Depth in Inches	Weight of Oven-dry Soil	Weight of Water	Per Cent Moisture	Volume Weight
4	238.4	25.5	10.7	1.0
5	224.1	23.9	10.7	1.0
6	253.4	28.1	11.1	1.1
7	235.6	26.5	11.2	1.0
8	195.7	21.0	10.7	0.8
Total	1488.5	158.8	10.7	
Calculated	1500.0	150.0	10.0	
Difference	—11.5	+8.8	+0.7	
Carton No. 2—300 grams water mixed with 1500 grams dry soil				
1	126.9	24.9	19.6	1.1
2	237.7	48.6	20.4	1.0
3	194.9	38.9	20.0	0.8
4	193.3	40.6	21.0	0.8
5	195.3	40.7	20.8	0.8
6	171.1	35.3	20.6	0.7
7	231.2	47.3	20.5	1.0
8	138.8	28.5	20.5	0.6
Total	1489.2	304.8	20.5	
Calculated	1500.0	300.0	20.0	
Difference	—10.2	+4.8	0.5	
Carton No. 3—375 grams water mixed with 1500 grams dry soil				
1	111.0	26.6	24.0	1.0
2	204.3	50.9	24.9	0.9
3	209.7	52.6	25.1	0.9
4	216.9	55.1	25.4	0.9
5	202.2	52.4	25.9	0.9
6	183.7	46.7	25.4	0.8
7	198.6	51.2	25.8	0.9
8	152.6	40.7	26.7	0.7
Total	1479.0	376.2	25.4	
Calculated	1500.0	375.0	25.0	
Difference	—21.0	+1.2	+0.4	
Carton No. 4—450 grams water mixed with 1500 grams dry soil				
1	142.6	44.5	31.2	1.2
2	185.2	57.7	31.2	0.8
3	227.4	70.6	31.0	1.0
4	195.9	60.8	31.0	0.8
5	213.5	60.8	28.5	0.9
6	196.9	61.6	31.3	0.8
7	191.7	60.7	31.7	0.8
8	111.4	35.7	32.0	0.5
Total	1464.6	452.4	30.9	
Calculated	1500.0	450.0	30.0	
Difference	—25.4	+2.4	+0.9	

TABLE II—Continued

Depth in Inches	Weight of Oven-dry Soil	Weight of Water	Per Cent Moisture	Volume Weight
Carton No. 5—600 grams water mixed with 1500 grams dry soil				
1	107.8	41.8	38.8	0.9
2	195.0	76.9	39.4	0.8
3	203.6	83.8	41.2	0.9
4	212.5	87.0	40.9	0.9
5	221.8	92.7	41.8	1.0
6	201.6	84.2	41.8	0.9
7	199.8	83.8	41.9	0.9
8	135.1	57.1	42.3	0.6
Total	1477.2	607.3	41.1	
Calculated	1500.0	600.0	40.0	
Difference	—22.8	+7.3	+1.1	

It should be noted, however, that although it appears possible to bring a soil to any desired moisture content by careful and thorough mixing, it is impossible to maintain this moisture content by adding water to the surface of the soil. Hence, if it were desired to grow a plant in a soil maintained at a constant and uniform moisture content (of, say, 20 per cent), it would be impossible to maintain this moisture content by adding to the surface of the soil an amount of water equivalent to that transpired by the plant.

Table III gives the results of an attempt to raise the moisture content of the soil from 20 per cent to 30 per cent by adding water at the surface of the soil. In this case, a specimen of Waipio soil with a moisture equivalent of 31.8 per cent was sifted, and its residual moisture content determined. Sufficient water was added to bring the soil moisture content on a basis of 1500 grams of oven-dried soil to 20 per cent. The soil and water were thoroughly mixed, and the mass placed in the container where it remained for 48 hours. To the soil surface in the container was added 150 grams of water, which theoretically should raise the moisture content of the soil to 30 per cent. The container again was allowed to stand for 48 hours, after which each soil increment was sampled as in the preceding studies.

It is obvious that a uniform increase in moisture content throughout the soil mass did not take place. The moisture content of the soil in the first 3 inches and part of the 4th was raised to a high moisture content, but the moisture content of the soil in the lower horizon is but slightly, if any, higher than that before irrigation. The fact that the ratio of moisture equivalent (31.8 per cent) to the soil moisture content of the upper horizon is greater than the customary constant of 1.1 may indicate that the soil and water were not yet in equilibrium after 48 hours. In view of the results of the previous studies, however, it seems unlikely that moisture would become uniformly distributed throughout the soil even if allowed to stand a longer time before sampling.

TABLE III

Distribution of Soil and Moisture after Sufficient Water was Added to Soil Surface to Raise Soil Moisture Content from 20 to 30 Per Cent

	Carton No. 1		Carton No. 2	
1″	45.0	44.9	43.5	45.6
2″	42.8	42.5	42.3	42.5
3″	53.2	39.4	38.2	37.6
4″	33.1	30.6	32.9	32.6
5″	29.2	27.6	28.8	26.9
6″	21.8	21.4	21.9	22.0
7″	21.3	21.2	21.3	22.0
8″	21.4	21.1	20.9	21.5

150 grams water added to surface of soil containing 300 grams water

Depth in Inches	Weight of Oven-dry Soil	Weight of Water	Per Cent Moisture	Volume Weight	"Relative Wetness" Pct. Moisture ×100÷ M. E. (31.8%)
			Carton No. 1		
1	116.8	52.5	45.0	1.0	141
2	188.2	80.3	42.6	0.8	134
3	196.7	91.2	46.4	0.8	145
4	208.3	66.5	31.9	0.9	100
5	200.6	57.0	28.4	0.9	89
6	239.8	51.8	21.6	1.0	68
7	170.3	36.2	21.2	0.7	67
8	154.2	32.8	21.3	0.7	67
Total	1474.9	468.3	31.8		
Calculated	1500.0	450.0	30.0		
Difference	—25.1	+8.3	1.8		
			Carton No. 2		
1	113.4	50.4	44.5	0.8	140
2	197.1	83.6	42.4	0.8	133
3	208.5	79.1	37.9	0.9	119
4	187.5	61.4	32.7	0.8	103
5	250.2	69.9	27.9	1.1	88
6	196.4	43.1	22.0	0.8	69
7	195.8	42.3	21.6	0.8	68
8	132.7	28.0	21.1	0.6	66
Total	1481.6	457.8	30.9		
Calculated	1500.0	450.0	30.0		
Difference	—18.4	+7.8	0.9		

Field Studies on the Distribution of Moisture After Irrigation

The studies reported in this paper are of a preliminary nature, and attempt to gain basic information on the manner and extent of soil moisture distribution in varied soil types and under various methods of irrigation. The method followed in these investigations was to irrigate a small area of dry soil. After an

interval of at least 24 hours, narrow trenches were dug to the required depth across the irrigated area. In most cases the line of demarcation between moist and dry soil could be seen plainly. The perimeter of the wetted soil zone was marked by pins in the face of the trench, and the position of each pin recorded and mapped. This method, which has been used successfully in similar mainland investigations (11, 15) was first used in Hawaii by T. K. Beveridge, of the Waimanalo Sugar Company.

Soil moisture samples were taken by pressing the rim of the sample tin into the face of the trench, thus procuring a fairly large sample with a minimum of disturbance or distortion of the soil. Two samples were taken from each position. One sample was weighed within 6 hours from the time of sampling, dried at 110° C. in an electric oven for 48 hours, and the total per cent moisture in the sample determined. The other sample, taken from the same position on the face of the trench, was divided into two parts and the moisture equivalent by the standard centrifuge method (9) determined in duplicate. The "Relative Wetness" or total per cent moisture $\times$ 100 $\div$ moisture equivalent was determined for each set of samples taken. The position on the trench face of each set of samples was recorded and mapped.

This method appears to reduce to a minimum errors caused by variation in the moisture-holding properties of the soil, which may occur within limited areas. The ratio between total moisture content and moisture equivalent rather than the moisture percentage itself is the figure which must be considered in these studies. As has been indicated previously, detailed investigations (6) on 28 distinctive soil types from Maui, Kauai and Oahu indicate that there is a remarkably constant relationship between the moisture equivalent and the total moisture content when the soil is at maximum field capacity shortly after irrigation. This relationship may be expressed as moisture equivalent $\times$ 1.1 = maximum field capacity. Hence, if the "Relative Wetness," or ratio between moisture equivalent and total moisture content multiplied by 100 is between 100 and 110, it is fairly assumed in these studies that the soil is close to its maximum field capacity. If the ratio is considerably higher than 110, it is inferred that the water and soil are not yet in equilibrium. If the ratio is considerably lower than 100, however, it appears evident that the soil in question probably has not received additional moisture from the irrigation and that the moisture content of the soil is below the maximum field capacity.

Moisture Distribution Under Contour Irrigation—Waipio Substation.

In a dry, plowed field at the Waipio substation, a series of three furrows 30 feet long, 5 feet wide from center to center, with ridges 12 to 16 inches high, were prepared. Each furrow was essentially level from end to end. Irrigation water was admitted to the head of each furrow from a tank, the volume of which was known accurately, so that the net application of water to an area 30 feet by 5 feet could be calculated. In each series, water was admitted only to the two outer furrows, the center furrow remaining dry. After an interval of 48 hours, trenches were dug at the head and at the foot of each series of furrows, the line

of demarcation between moist and dry soil plotted, and soil moisture samples taken as indicated in the accompanying graphs.

Fig. 1 indicates the distribution of moisture after a light irrigation of 1.34 acre inches per acre. The wetted zone assumes an elliptical shape with its major axis in a horizontal direction. Although there is little difference in color or texture between surface soil and subsoil in the fine, well-drained Waipio loam, the increased density of the soil below the plow limits appears to be sufficient to check slightly the downward movement of water and to allow a lateral movement for 20 or 30 inches to each side of the center of the furrow. The vertical penetration of water under an application of 1.34 acre inches per acre did not exceed 18 inches below the bottom of the furrow.

Under a somewhat heavier irrigation application of 2.00 acre inches per acre (Fig. 2), the lateral movement of water 48 hours after irrigation was not appreciably greater than that under the lighter application, and in most cases did not exceed 20 to 24 inches from the center of the furrow. Apparently the denser subsoil did not exert a checking effect on the downward penetration of water under the heavier irrigation. The shape of the wetted zone changed considerably under the 2.00 acre inch per acre application. The zone became more cup-shaped in appearance, the lateral movement of moisture was not increased, but the vertical penetration of water increased to slightly over 30 inches below the bottom of the furrow.

A heavy application of 4.00 acre inches per acre to the third series of furrows (Fig. 3) caused the entire furrow to be filled with water. The zone of moisture distribution 48 hours after irrigation is significantly different in shape than the two discussed previously. The general shape of the wetted zone appears nearly circular, the lateral movement increased to 30 or 35 inches, and the vertical penetration was nearly 50 inches below the bottom of the furrow. It is significant to note that it is only in this last case with a heavy application of water that the lateral spread is great enough for the wetted zones to overlap, had the center furrow been irrigated. The vertical penetration of moisture in this case, however, was probably far greater than the roots of any but mature plants could reach. It would seem to follow that in order to obtain a lateral belt of wetted soil entirely across a series of furrows under the contour method of irrigation, that it would be necessary to apply water so heavily that a considerable amount would be lost by deep percolation. It is also worthy of note that in no case did the zone of wetted soil extend far into the ridge between furrows. Soil moisture samples indicate that under the conditions of this experiment no water was added to the ridges by lateral movement or by capillary attraction from the irrigated furrows. It would thus appear that, under prolonged periods of no rainfall, cane "hilled up" on the ridge between furrows must depend on a considerable lateral spread of roots to the wetted zone for its supply of moisture and soluble nutrients.

The soil moisture samples and the "Relative Wetness" ratio between moisture equivalent and total moisture content seems to lead toward several interesting conclusions. The position from which samples for total moisture content and for moisture equivalent determinations were taken from the face of the trench is indicated on the graphs by circles. The figure above each circle is the total per cent

moisture of the soil at that point, the figure below the circle is the average of duplicate moisture equivalent determinations which may be considered an approximate of the maximum field capacity of the soil, and in the center of the circle is given the "Relative Wetness" ratio between the two figures.

It will be noted immediately that the "Relative Wetness" of the soil within the wetted zone is close to 100; in other words, the soil is at its maximum field capacity. There does not appear to be any consistent variation in the value of the ratio from point to point within the wetted zone. In view of investigations elsewhere (10, 11, 15) and the results of laboratory investigations on Waipio soil reported earlier in this paper, it seems fair to assume that each increment of soil in both a lateral and vertical direction must have been wetted to its maximum field capacity before the next increment received any moisture. The ratio of the samples taken just outside the perimeter of the wetted zone is, in general, considerably lower than that within the perimeter, although the positions of the two samples may be separated by but a few inches. The inference may surely be drawn that the soil outside the perimeter of the wetted zone has not received any moisture within 48 hours after the irrigation application has been made. In some cases (see particularly Fig. 1), the "Relative Wetness" of samples outside the perimeter of the wetted zone and generally at the lower soil depths may be relatively high, and indicates in some cases that the soil is at its maximum field capacity. It would seem not unlikely that the soil of the lower horizons may have been wetted by previous rainfall and irrigation, the moisture from which had never been depleted by the root action of the previous crop. This belief seems to be supported by moisture samples taken below the center furrow which was not irrigated, and which bear "Relative Wetness" ratios indicating that the residual soil moisture was already at maximum field capacity.

Role of Capillarity in Soil Moisture Distribution.

For many years the faith of farmers, many scientists, and a large number of agricultural text-books have been firmly pinned on the effectiveness of capillarity in providing a lateral and vertical movement of water through the soil to plants. This movement of moisture, based on the theory of surface tension, popularly is believed to carry water laterally through the soil and vertically against the force of gravity for indefinite distances above the subterranean water table. The general confidence in capillary attraction as a means of conveying water through the soil doubtlessly may be ascribed to laboratory demonstrations of the rise of moisture from a free water surface through small columns of soil. That such a movement of water exists for a limited distance from a free water table cannot be doubted, but that capillary attraction is an effective force in the movement of water from moist to dry soil is now generally discredited, (15, 16, 17, 18, 19, 20, 21, 22). Agricultural scientists from the time of King in 1889 and Loughridge in 1894 to contemporary investigators have shown that the lateral and vertical movement of water by capillarity is extremely limited both in rate and extent, and that its value in supplying water to plant roots, except for a short distance above a free water table, is negligible.

In order to determine if capillarity might be considered as a contributing factor in the distribution of moisture through the Waipio loam reported here, soil moisture samples just outside the perimeter of the wetted zone were taken five days after irrigation. The face of each trench, which had been covered to prevent evaporation, was scoured by a cane knife so that all exposed surface was removed and a fresh soil surface presented for sampling. Soil samples were taken for both total moisture content and moisture equivalent as described previously. The position of each set of samples is shown in Figs. 1, 2 and 3 as a dotted circle, and the results of the analysis shown in the same manner as the previous series of samples.

The "Relative Wetness" ratio of the samples, taken just outside the perimeter of the wetted zone five days after irrigation water was applied to the area, indicates that no movement of moisture had taken place after 48 hours. Although the samples were taken but a few inches from the wetted zone as determined 48 hours after irrigation, the "Relative Wetness" shows that the soil was far below maximum field capacity and had not changed appreciably from that of samples taken in the same relative position three days previously.

From these results, it seems safe to conclude that no significant movement of moisture in either a lateral or vertical direction had taken place in the Waipio soil studied after 48 hours from the time of irrigation. It would appear, consequently, that little reliance may be placed in capillary action as a means of conveying water through a loam soil of the Waipio type.

Distribution of Soil Moisture Under Long-line Irrigation— Waimanalo Sugar Company

In a newly plowed field of heavy brownish-black soil on the plantation of the Waimanalo Sugar Company, a similar investigation on the distribution of soil moisture under long-line irrigation was made. Furrows 300 feet long on a 2 per cent slope were made by hand. The furrows were flat and shallow, the ridges seldom being more than 10 inches higher than the bottom of the furrow. For the purpose of the investigation, the furrows were made 10 feet apart, but are shown on the accompanying graphs as 50 inches from center to center. A normal irrigation application was made by plantation laborers. Measurements by a portable one-foot weir indicated an average net application of about 1.5 acre inches per acre, but there appeared to be some variation in application from furrow to furrow.

Twenty-four hours after irrigation, narrow trenches were dug across the furrows at distances of 50, 150 and 300 feet from the level ditch. The perimeter of the wetted zone, which was clearly visible on the face of the trench in all cases, was marked and plotted, and soil moisture samples were taken in the same manner as that described in the investigation on contour irrigation.

An examination of Figs. 4 and 5 reveals that the shape of the wetted zone under long-line irrigation somewhat resembles that from the light application of water under contour irrigation (Fig. 1). The wetted zone is elliptical in shape with the major axis in a horizontal direction. The vertical penetration under the irrigation given did not exceed 20 inches, and averaged approximately 12 inches

below the bottom of the furrow. A dense subsoil close to the surface apparently encouraged lateral percolation after the light application of water given, but in few cases was the lateral movement over 20 inches, and the average about 15 inches, to each side of the center of the furrow. In no case was the lateral penetration sufficient for the wetted zones of adjacent furrows to overlap even if furrows 50 inches apart were used. It is noteworthy that the distribution of water at various distances from the level ditch is not significantly different, and that the area of moisture penetration seems comparable whether the point examined was 50, 150 or 300 feet from the head of the furrow. In the cases where the wetted zone is relatively small, notably in line 4 at 300 feet, line 6 at 300 feet, line 7 at 50 and 150 feet, line 8 at 150 feet and line 10 at 150 feet, the contributing factor appeared to be an increased slope in the furrow for a short distance rather than the length of the furrow from the level ditch.

An analysis of the soil moisture data supports the general considerations stated earlier in this paper. The "Relative Wetness" of the soil within the perimeter of the wetted zone ranges in most cases from 100 to 110, indicating that the soil is at its maximum field capacity. The fact that the value of the ratio does not vary significantly from point to point within the wetted area seems to show that every increment of soil within the perimeter has been brought to the same degree of wetness before any further movement of moisture has taken place. The ratios between samples taken immediately outside the wetted zone are relatively low, and demonstrate that the soil immediately adjacent to the visible area of moisture distribution is far below its maximum field capacity and in all probability has never received any water from the current irrigation. There is no evidence of any movement of water into the ridges between furrows.

Time was not available for a study of the effect of capillary action on the distribution of moisture in this Waimanalo soil. However, investigations on the moisture distribution 300 feet from the head of the furrow were not made for 96 hours after irrigation. There is no evidence, either from increased spread of the wetted zone or from greater values for the "Relative Wetness" of samples taken a few inches outside the perimeter of the wetted area, to indicate a progressive movement of moisture in any direction. It would be difficult to conceive, therefore, that capillarity might be a potent factor in the movement of moisture from moist to dry soil or in supplying an appreciable quantity of water to plant roots some distance away from the wetted zone.

Distribution of Soil Moisture Under the Border Method of Irrigation—Ewa Plantation Company

Studies of moisture distribution under the border method of irrigation were conducted in a fine, brown loam field of the Ewa Plantation Company. The width of each border was 20 feet, and the length about 1200 feet. The general slope of the borders was about 1.5 per cent. Unfortunately, there was no opportunity to study the moisture distribution after the first irrigation to a dry field as had been the case with investigations under contour and under long-line irrigation reported in this paper. The cane in the area studied was about 5 or 6 feet high,

and had 15 irrigations prior to the period of the investigation. Seven adjoining borders were chosen for the investigation. Borders numbered 2, 4 and 6 were irrigated by plantation laborers who made a normal application of water. The intervening borders remained unirrigated so that a determination of the lateral movement of irrigation water might be made.

Trenches were dug across each irrigated border and for some distance into the unirrigated borders on either side at points 100 feet from the level ditch, at the center of the border about 600 feet from the level ditch, and at a point some 200 feet from the end of the border. The trenches were excavated not sooner than 48 hours after irrigation. It was apparent, from an inspection of the face of each trench, that it would be impossible to determine the exact extent of moisture penetration from the current irrigation as had been done in the previous investigations. It has been found difficult, by those using the border method of irrigation, to vary appreciably the quantity of water applied in each irrigation during the first few months of the crop. The necessity for a complete distribution of irrigation water from side to side on the surface of the border makes it imperative that the irrigation application does not fall below a certain minimum, depending on the soil type, the grade, and the level from side to side of the border, which will insure an adequate distribution of water on the surface of the border. Hence it frequently happens that there is no significant difference between the quantity of water applied in the first irrigation to plant cane and that to the same area some months later when the plant must be consuming a much greater amount of soil water. It would naturally follow that such quantities of water applied in early irrigations and not used by the feeding roots of the plant pass to the lower soil horizon until each successive increment of soil is filled to its maximum field capacity. As more of such excessive applications of water are made, the water probably percolates through the soil until it reaches the subterranean water table. In view of the preceding evidence on the failure of capillary attraction to convey water for any distance through the soil, it appears improbable that any water penetrating below the normal root range is ever recovered by the plant.

It would thus appear that much of the water applied in early irrigations by the border method may function purely as a mechanical means of distributing the application over the entire surface of the border, and that relatively little of the total water applied may be available to the plant. Such would be the opinion gained from an inspection of the trenches across the borders in this investigation. It was impossible to distinguish the wetted area caused by the current irrigation from that caused by previous applications of water. Although the trenches were dug to a depth of six or seven feet there appeared no change in the relative moistness of the soil, and each increment of soil to an indefinite depth appeared to be at its maximum field capacity. Soil moisture results support this observation. Figs. 6, 7 and 8 show the position of each set of samples with the values for total per cent moisture, moisture equivalent, and "Relative Wetness" as described for the previous investigations. In the vertical soil area immediately below the irrigated bed of the border, the value of the "Relative Wetness" of the soil with but few exceptions lies between 100 and 110, indicating that the entire soil mass to an indefinite depth below the border was at maximum field capacity. It appears

probable that the few exceptions in which the value of the "Relative Wetness" ratio lies between 80 and 100 might be caused by a reduction of soil moisture by the feeding roots of the plant, and are too infrequent to intimate any significant exception to the observations noted. From the low value for the "Relative Wetness" of samples taken below the levee between borders and from the adjacent unirrigated borders, it appears probable that but little lateral movement of moisture took place as the soil at these points is generally below its maximum field capacity. At depths of from 8 to 10 feet in some of the trenches there was evidence of a localized or "perched" water table possibly caused by accumulations of excess water in the subsoil shortly after an irrigation. In such a case, capillary action might be effective in the distribution of moisture for a limited distance above the free water table.

Observations in the trenches 200 feet from the end of the borders indicated that there might be a relatively inadequate distribution of moisture and the formation of a hardpan in the subsoil. Whether the hardpan formation (which was not apparent at other points in the border) might have been caused by an inadequate penetration of water during previous irrigations or whether the inadequate distribution might be caused by the hardpan is difficult to determine. With the technique now used in border irrigation, the water is turned off at the headgate when the advancing sheet of water is yet some distance from the end of the border. It seems not unlikely that there may be a short distance, between the position of the advancing water at the time the suppply was stopped and the point at which the water backs up from the end of the border, at which the penetration of water might be inadequate, and a modification of the colloidal properties of the soil such as to cause a hardpan formation might occur. Such a zone of inadequate penetration near the end of the border is often reflected in reduced cane growth under the border method of irrigation.

Conclusions

The investigations reported here on the soil moisture distribution in three distinct soil types and under three methods of irrigation are of such a preliminary nature that it would be inadvisable and dangerous to attempt to draw definite conclusions from them. The evidence appears sufficient, however, to warrant the following suggestions on this important subject:

1. Some of the factors which appear to have direct bearing on the distribution of soil moisture after irrigation are: the nature, depth and texture of surface soil and subsoil, the slope and gradient of the land, and the depth of the free water table below the ground surface. The nature and depth of the subsoil below the surface appear to have a decided effect on the shape of the wetted zone, particularly after light irrigations.

2. Laboratory studies on a Waipio soil indicate that each increment of soil must be brought to its maximum field capacity (or greatest amount of water that can be held by the soil against the force of gravity) before other increments of soil can be wetted. As a corollary, it would appear that it is impossible to irrigate a soil, whether in the field or in pot cultures, to any moisture content lower than its maximum field capacity.

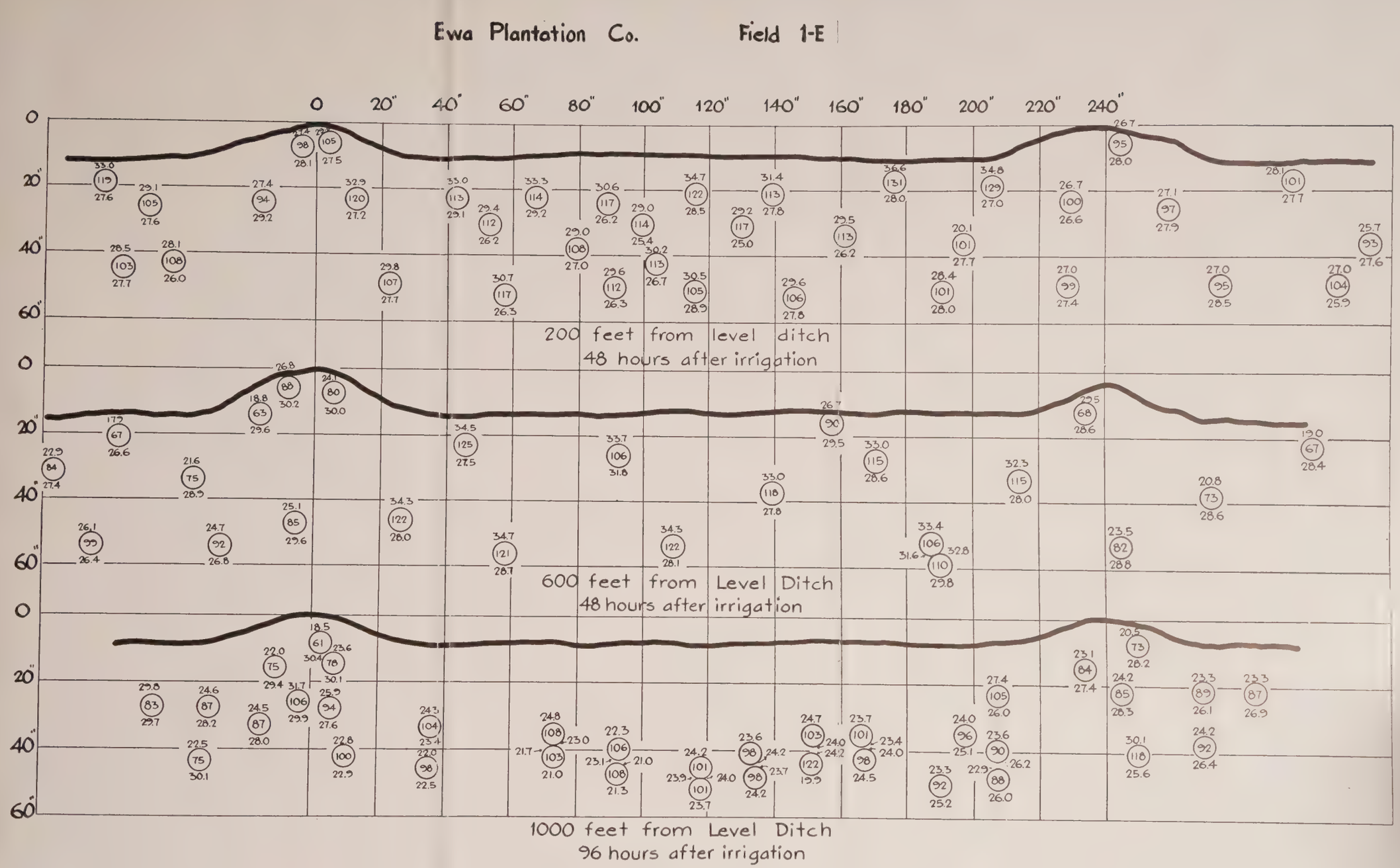
DISTRIBUTION OF SOIL MOISTURE UNDER BORDER IRRIGATION
Ewa Plantation Co. Field 1-E
0 20" 40" 60" 80" 100" 120" 140" 160" 180" 200" 220" 240"
0
20"
40"
60"
200 feet from level ditch
48 hours after irrigation
600 feet from Level Ditch
48 hours after irrigation
1000 feet from Level Ditch
96 hours after irrigation

Fig. 6

DISTRIBUTION OF SOIL MOISTURE UNDER BORDER IRRIGATION

Ewa Plantation Company—Field I E

Circles represent position of soil moisture samples.
Figure above circle—total percentage soil moisture.
Figure below circle—average of duplicate Moisture Equivalent determinations.
Figure in circle—"Relative Wetness" or Total Moisture × 100 ÷ Moisture Equivalent.

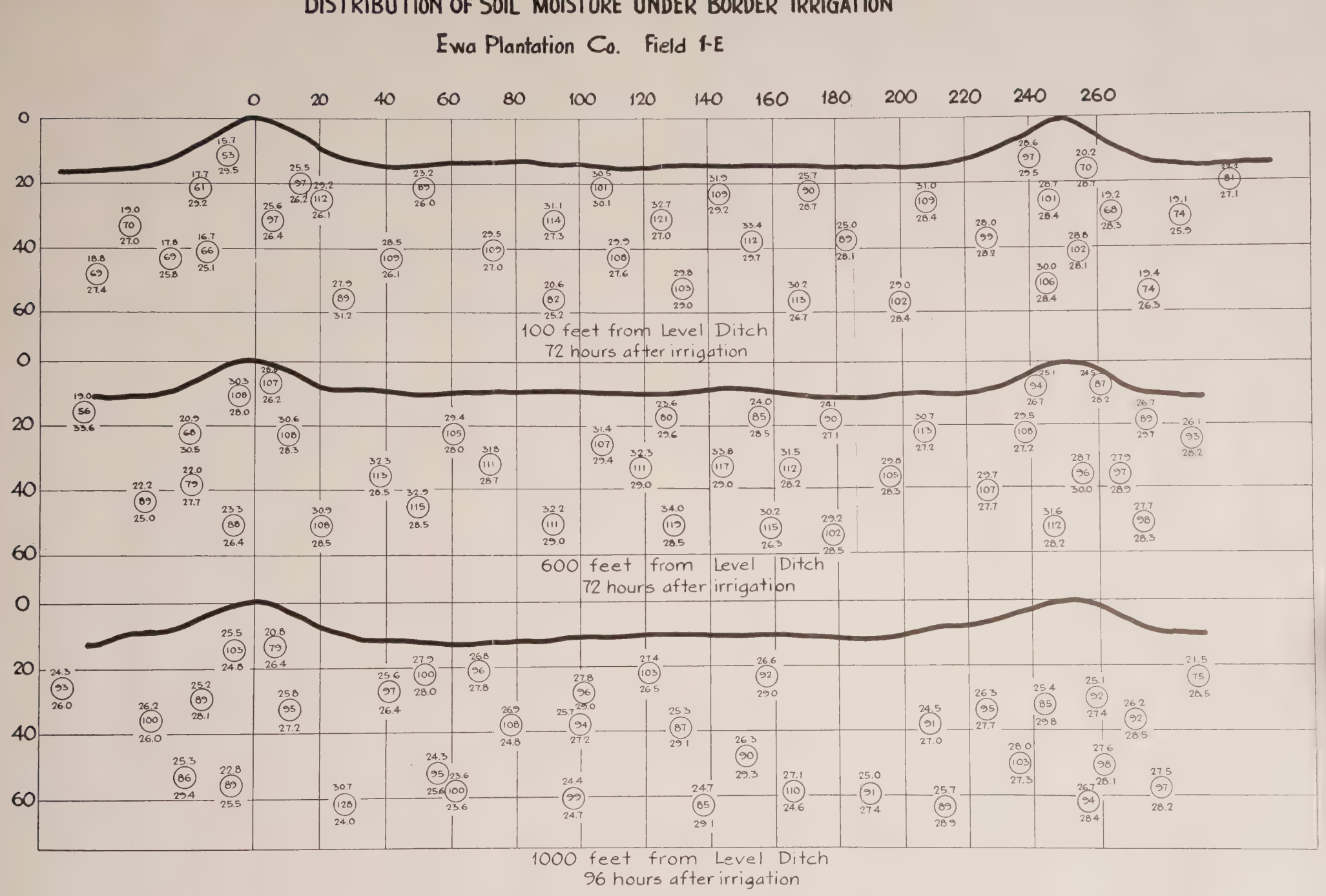
DISTRIBUTION OF SOIL MOISTURE UNDER BORDER IRRIGATION
Ewa Plantation Co. Field 1-E
0 20 40 60 80 100 120 140 160 180 200 220 240 260
0
20
40
60
100 feet from Level Ditch
72 hours after irrigation
600 feet from Level Ditch
72 hours after irrigation
1000 feet from Level Ditch
96 hours after irrigation

Fig. 7

DISTRIBUTION OF SOIL MOISTURE UNDER BORDER IRRIGATION

Ewa Plantation Company—Field I E

Circles represent position of soil moisture samples.
Figure above circle—total percentage soil moisture.
Figure below circle—average of duplicate Moisture Equivalent determinations.
Figure in circle—"Relative Wetness" or Total Moisture × 100 ÷ Moisture Equivalent.

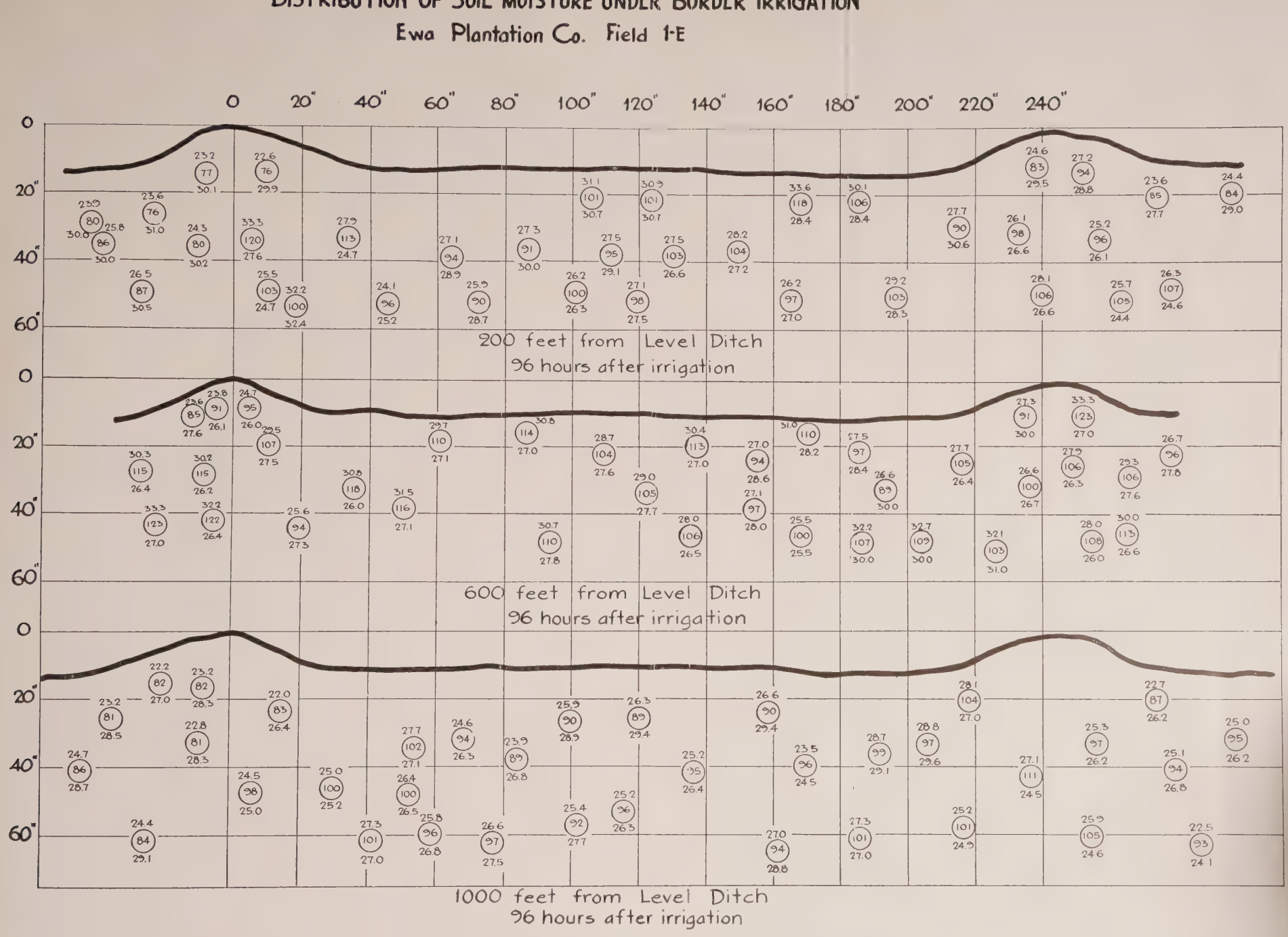
DISTRIBUTION OF SOIL MOISTURE UNDER BORDER IRRIGATION
Ewa Plantation Co. Field 1-E
0 20" 40" 60" 80" 100" 120" 140" 160" 180" 200" 220" 240"
0
20"
40"
60"
200 feet from Level Ditch
96 hours after irrigation
600 feet from Level Ditch
96 hours after irrigation
1000 feet from Level Ditch
96 hours after irrigation

Fig. 8

DISTRIBUTION OF SOIL MOISTURE UNDER BORDER IRRIGATION

Ewa Plantation Company—Field I E

Circles represent position of soil moisture samples.
Figure above circle—total percentage soil moisture.
Figure below circle—average of duplicate Moisture Equivalent determinations.
Figure in circle—"Relative Wetness" or Total Moisture × 100 ÷ Moisture Equivalent.

3. After a light irrigation to a normal loam soil by the contour or the long-line methods of irrigation, the wetted area is elliptical in shape with its major axis in a horizontal direction. With heavier applications of water, the lateral spread of moisture does not increase materially but the vertical penetration increases in rough proportion to the intensity of the application.

4. The soil moisture analyses presented in this paper are based on the ratio between the moisture equivalent, a laboratory determination which appears to be a relatively reliable index of the moisture-holding properties of a given soil, and the total percentage moisture in the same soil. This ratio, termed the "Relative Wetness" appears to be a fair criterion of the degree of moistness in a soil.

5. Evidence from this investigation indicates that the soil at all points within the wetted area caused by the irrigation is at its maximum field capacity. The soil immediately outside the perimeter of the wetted zone is considerably below its maximum field capacity, and in all probability receives no water from the current irrigation. Such evidence supports the results noted in paragraph 2: that each increment of soil must be wetted to its maximum field capacity before other soil increments receive any water.

6. There is no evidence from this investigation to indicate that in a well-drained loam soil there is any appreciable movement of water from moist to dry soil by means of capillary attraction. It is suggested that the effectiveness of capillarity in the movement of soil moisture should not be overestimated.

7. Under the contour and the long-line methods of irrigation, the lateral penetration of water in the soil did not exceed 30 inches and was seldom more than 20 inches to each side of the center of the furrow. It seems probable that "hilled up" cane on the ridges between furrows must depend, during prolonged periods of low rainfall, on a considerable lateral root extension to the wetted area for an adequate supply of soil moisture and soluble nutrients.

8. From studies of an Ewa soil under the border method of irrigation it would appear that the soil mass immediately below the bed of the border and to an indefinite depth was at its maximum field capacity although the lateral spread of moisture appears to be limited. It seems, however, that the quantity of water required for an adequate surface distribution of water under the border method of irrigation may be greater than the requirement of the crop, resulting in accumulations of excess water at the lower soil depths, which may never become available to the plant.

9. The methods of investigation reported in this paper are suggested to plantations interested in the distribution of moisture in their soils under various methods of irrigation as a comprehensive and apparently reliable means of irrigation research.

Acknowledgments

The writer is indebted to George Chalmers, manager, and T. K. Beveridge, agriculturist, of the Waimanalo Sugar Company; and to George F. Renton, manager, J. B. Menardi, Jr., and Bert Bacon, agriculturists, of the Ewa Plantation Company, for the authority and cooperation necessary in the completion of the investigations on their plantations.

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Annual Synopsis of Mill Data

By W. R. McAllep and W. L. McCleery

This Synopsis includes operating data for all factories in the Association for the year ending September 30, 1931. These 39 factories produced 99.4 per cent of the total Hawaiian crop. Synopsis data represent the production of 987,314 tons of sugar, an increase of 7 per cent over the previous record of last season.

Following the practice of alternating the factory equipment table and the table of roller grooving and returner bar settings, the former has been included in this Synopsis and the latter has been omitted. Table 3 is given again, but in briefer form, only figures of particular significance in making comparisons being retained. This is a tabulation of true averages for the factories where the control is based on the mixed juice, factories where the basis of control was changed to clarified juice following the introduction of the Petree process being excluded.

As usual, factories are listed in most of the tables according to the average production during the previous five years.

Varieties of Cane

The number of varieties amounting to 1 per cent or more of the crop remains at six, the same as last year. P. O. J. 36 has replaced Badila in the Major Variety Table. P. O. J. 36 has been spread quite rapidly in certain areas, chiefly on Hawaii and Kauai, so that in the six years since its release from quarantine the tonnage has increased to 2.6 per cent of the total. Badila, which appeared as a major variety for the first time last year, has this year supplied slightly less than 1 per cent of the cane harvested. Acreage data indicate that in the next two years the tonnage of Badila should approximate 1 per cent of the total quite closely.

H 109 appears to have reached a maximum. In the past five seasons the proportion has fluctuated between 53.1 and 56.6 per cent, with 54.2 per cent this year. The gradual decline of Yellow Caledonia has continued. This year the per cent was 18.8. Ten years ago it was 45. It is still the leading variety on nine plantations.

D 1135 has increased to 13.7 per cent, a figure slightly higher than has been reported previously. This cane has fluctuated between 10 and 13.7 per cent with a slight upward trend for the past 12 years. It is still the most widely distributed variety, being reported this year from 26 factories. Yellow Tip decreased and Striped Tip increased slightly. The trend for both of these canes appears downward.

TABLE NO. 1
MAJOR VARIETIES OF CANE
(One per cent or more of total crop)

	H 109	Y. C.	D 1135	Yellow Tip	P. O. J. 36	Striped Tip	Others
H. C. & S. Co.	99	...	1	...	...	...	...
Oahu	90	...	10	...	...	...	...
Ewa	96	...	...	...	...	...	4
Waialua	96	...	3	...	...	...	1
Maui. Agr.	100	...	...	...	...	...	...
Pioneer	100	...	...	...	...	...	...
Olaa	...	72	28	...	...	...	...
Lihue	51	...	4	15	13	...	17*
Haw. Sug	94	...	6	...	...	...	...
Honolulu	98	...	...	...	2	...	...
Kekaha	98	...	...	...	...	...	2
Haw. Agr.	...	33	51	...	1	...	15
Onomea	...	76	10	9	4	...	1
Hilo	...	88	11	1	...	...	...
Makee	61	9	...	8	9	...	13
Honokaa	2	4	66	...	8	...	20†
Wailuku	87	1	3	...	...	...	9
McBryde	76	3	5	1	1	...	14
Hakalau	...	72	13	15	...	...	...
Laupahoehoe	...	34	54	11	...	...	1
Kahuku	97	3	...	...	...	...	...
Koloa	54	3	...	24	15	...	4
Waiakea	...	99	1	...	...	...	...
Pepeekeo	...	98	2	...	...	...	...
Hamakua	...	17	76	6	...	...	1
Paauhau	...	1	65	7	19	...	8
Hutchinson	...	60	25	...	14	...	1
Kohala (Hawi)	...	...	21	...	2	63	14‡
Honomu	...	79	18	...	1	...	2
Kohala	1	1	20	...	...	16	62§
Kaiwiki	...	9	75	13	...	...	3
Waimanalo	71	...	...	...	20	...	9
Kilauea	4	1	4	20	6	2	63¶
Waianae	100	...	...	...	...	...	...
Kaeleku	...	100	...	...	...	...	...
Union Mill	...	...	17	4	78	...	1
Niulii	...	6	54	5	1	34	...
Waimea	100	...	...	...	...	...	...
Olowalu	92	...	...	...	5	...	3
True Average 1931	54.2	18.8	13.7	3.0	2.6	2.1	5.6
" " 1930	56.6	19.9	12.3	3.5	0.7	1.6	5.4
" " 1929	53.1	21.5	13.0	4.3	0.3	2.1	5.7
" " 1928	54.7	20.7	12.9	4.9	...	2.2	4.6
" " 1927	53.1	23.7	11.8	4.0	...	1.6	5.8
" " 1926	48.7	25.6	12.1	4.5	...	2.1	7.0
" " 1925	42.7	30.7	11.9	2.7	...	2.1	9.9
" " 1924	38.1	32.6	12.0	2.3	...	2.0	13.0
" " 1923	30.7	36.3	11.2	1.2	...	1.6	19.0
" " 1922	21.1	40.3	12.2	2.7	...	1.6	22.1

* Badila, 7%; H 456, 6%
† Uba, 15%
‡ K 107, 13%
§ K 107, 55%; K 202, 6%.
¶ Uba, 28%.

Varieties comprising 1 per cent or more of the crop at any factory, but less than 1 per cent of the total crop, are listed below:

MINOR VARIETIES

One Per Cent or More of the Crop at Any Factory

1. K 107	6. H 9806	10. UD 1	14. Rose Bamboo
2. Uba	7. K 202	11. Wailuku 4	15. Wailuku 2
3. Badila	8. St. Mex.	12. McBryde 7	16. Nalo 44
4. H 456	9. H 8965	13. McBryde 1	17. D 117
5. P. O. J. 213			

Varieties are listed in the order of their tonnage as reported. Percentages are not given as there are indications that minor variety figures in factory reports are incomplete and that the percentages would be misleading. This list accounts for about 70 per cent of the tonnage listed as "Others" in Table 1.

Lahaina, which dropped out of the major variety classification in 1928, has been omitted from the minor variety table this year. It was reported from two factories, but in neither instance did it amount to 1 per cent of the crop. H 5909 and Manoa 213, previously appearing as minor varieties, are not included this year. Additions are H 9806, Wailuku 2 and Nalo 44. D 117, which was formerly a major variety, is now reported from only one factory, and Rose Bamboo, also a former major variety, is reported from but two factories.

Quality of Cane

The average quality ratio has improved slightly since last season. It is better than in 1927 and the same as in 1928, but considerably poorer than in other years. The improvement over last year is due to a moderate increase in pol, which has more than offset a decrease of .57 in purity.

The first expressed juice purity is now down to 86.47, the lowest figure in four years. Lower purities have been reported in but two previous seasons.

The average fiber has decreased .10. The present figure is close to the minimum reported in the past ten years.

Juice purities have decreased on all of the Islands. Cane pol also has decreased on Kauai, but has increased on each of the other islands. On Oahu the increase in pol has exactly offset the decrease in purity, leaving the quality ratio unchanged. On Hawaii and Maui smaller decreases in purity and larger increases in pol have resulted in better quality ratios. On Kauai the decreases in both pol and purity have resulted in a materially lower quality. We thus have had better cane on Hawaii and Maui, poorer cane on Kauai and the same quality on Oahu. These changes are tabulated below. They are expressed as Yields per cent Cane, calculated on the same basis as quality ratio, for Yield per cent Cane expresses differences in quality more accurately than the reciprocal quality ratio figures.

TABLE NO. 2

COMPOSITION OF CANE BY ISLANDS

	Hawaii	Maui	Oahu	Kauai	Whole Group
1922					
Pol	12.07	13.95	13.61	13.03	12.97
Per cent Fiber	13.16	12.38	12.88	13.22	12.95
Purity 1st Expressed Juice	87.17	87.88	86.18	85.80	86.84
Quality Ratio	9.11	7.70	7.99	8.30	8.39
1923					
Pol	12.09	13.61	12.99	12.94	12.78
Per cent Fiber	13.14	12.01	12.86	12.99	12.82
Purity 1st Expressed Juice	87.61	88.65	85.52	86.58	87.05
Quality Ratio	9.04	7.86	8.43	8.36	8.50
1924					
Pol	12.44	14.34	13.48	13.34	13.26
Per cent Fiber	12.99	12.16	12.72	12.94	12.74
Purity 1st Expressed Juice	87.98	89.19	87.02	87.31	87.86
Quality Ratio	8.78	7.53	8.10	8.06	8.19
1925					
Pol	12.35	14.42	13.52	13.24	13.22
Per cent Fiber	12.92	12.40	12.60	12.91	12.74
Purity 1st Expressed Juice	88.02	89.36	87.11	87.19	87.92
Quality Ratio	8.84	7.42	8.12	8.15	8.22
1926					
Pol	12.53	14.66	13.40	13.03	13 24
Per cent Fiber	12.90	12.24	12.72	12.46	12.65
Purity 1st Expressed Juice	87.59	89.03	86.61	86.68	87.45
Quality Ratio	8.73	7.36	8.23	8.33	8.24
1927					
Pol	11.34	14.00	12.61	12.07	12.32
Per cent Fiber	12.84	11.98	12.29	12.65	12.49
Purity 1st Expressed Juice	86.27	87.85	85.87	85.17	86.28
Quality Ratio	9.73	7.71	8.78	9.11	8.91
1928					
Pol	11.57	14.13	13.09	12.09	12.55
Per cent Fiber	12.58	12.56	12.13	12.82	12 50
Purity 1st Expressed Juice	86.60	88.76	86.84	85.16	86.84
Quality Ratio	9.54	7.55	8 39	9.11	8.72
1929					
Pol	11.80	14.56	13.49	12.64	12.90
Per cent Fiber	12.53	13.24	12.28	12.61	12.62
Purity 1st Expressed Juice	86.65	89.14	87.17	85.97	87 18
Quality Ratio	9.45	7.35	8.14	8.69	8.50
1930					
Pol	11.30	13.77	13.05	12.67	12.49
Per cent Fiber	12.73	12.92	12.35	12.57	12.63
Purity 1st Expressed Juice	86.59	88 60	86.98	86.34	87.04
Quality Ratio	9.84	7.79	8.42	8.55	8.76
1931					
Pol	11.51	14.30	13.17	12.55	12.63
Per cent Fiber	12.52	13.04	11.98	12.75	12.53
Purity 1st Expressed Juice	86.18	88.26	86 31	85.49	86.47
Quality Ratio	9.66	7.52	8.42	8.73	8.72

Note: Quality ratio calculated according to formula in 1931 Methods of Control.

TABLE NO. 3

True averages of all factories except those basing control on clarified juice

	1926	1927	1928	1929	1930	1931
First Expressed Juice—						
Brix	18.24	17.17	17.45	17.76	17.36	17.57
Pol	15.88	14.74	15.08	15.40	15.04	15.13
Purity	87.05	85.84	86.41	86.69	86.68	86.10
"Java ratio"	81.8	81.7	81.6	82.1	81.5	81.8
Mixed Juice—						
Brix	13.65	12.88	13.04	13.29	12.98	13.13
Pol	11.48	10.67	10.89	11.15	10.87	10.93
Purity	84.12	82.88	83.47	83.89	83.73	83.21
Weight % cane	110.10	109.71	109.87	110.18	109.77	110.28
Pol % cane	12.64	11.71	11.96	12.29	11.93	12.05
Extraction	97.27	97.23	97.24	97.28	97.25	97.36
Extraction ratio	21.5	22.1	22.1	21.7	21.8	21.2
Last Expressed Juice—						
Pol	2.06	1.88	1.94	1.99	1.94	2.01
Purity	68.72	67.76	68.39	68.73	68.54	68.19
Imbibition water % cane	32.54	32.04	31.99	32.44	32.15	32.23
Syrup—						
Brix	64.21	62.91	63.05	63.38	64.09	64.16
Purity	85.49	84.54	84.86	85.24	85.17	84.57
Increase in purity	1.37	1.66	1.39	1.35	1.44	1.36
Lbs. avail. CaO per ton cane	1.66	1.52	1.46	1.38	1.30	1.37
Press Cake—						
Pol	2.49	2.22	2.34	2.27	1.82	1.65
Weight % cane	2.63	2.67	2.87	2.87	2.96	2.99
Pol % cane	0.07	0.06	0.07	0.07	0.05	0.05
Pol % pol of cane	0.50	0.49	0.55	0.52	0.44	0.40

YIELD PER CENT CANE

	1930	1931	Difference
Hawaii	10.16	10.35	+ .19
Maui	12.84	13.30	+ .46
Oahu	11.88	11.88	.00
Kauai	11.70	11.46	— .24

These changes are in the opposite direction to those recorded last year. They have not been large enough to alter the usual ranking of the islands in quality of cane.

Fiber has decreased on Oahu and Hawaii. Figures for both islands are the lowest since fairly complete data have been compiled. Fiber has increased on Kauai and Maui; on Maui it is higher than in any previous year except 1929.

The quality ratio formula has been changed slightly in the 1931 Methods of Control. Figures in this Synopsis are on the new basis. The new quality ratios are slightly lower, thus indicating a slightly higher yield. Within the range of figures in Table 2, differences vary from .04 to .08, the larger differences being for the poorer quality cane.

Chemical Control

The trend toward more complete control figures continues. A larger number of factories have reported sucrose, pH, and turbidity data and there have been increases in the number of factories weighing mixed juice and molasses.

The control is on a sucrose basis at 35 factories, or two more than previously. Hawi, Kaeleku, Niulii and Waimea are the only factories remaining where the control is not on a sucrose basis.

Mixed juice is weighed at one additional factory, bringing the total to 37, and leaving only Kohala and Kaeleku that do not weigh mixed juice.

Molasses is weighed at 31 factories, an increase of two. Molasses weights are calculated from measurements at seven factories. One factory only has failed to report either weights or measurements. Molasses data from a second factory, however, have been omitted from the averages as the weights had not been corrected for stock in process.

All factories have reported complete pH data for the first time. Thirty-two have reported the turbidity of clarified juice against 27 last year.

The usual comparisons of boiling house recoveries with calculated theoretical recoveries are in Tables 4 and 5. In considering figures in these tables it is necessary to bear in mind that the calculated theoretical figure for sucrose recovery is slightly lower than what we might term the actual theoretical figure on account of deficiencies in our control methods. Likewise, the calculated theoretical figure for molasses is too high.

The trend in the past 10 or 12 years has been toward higher figures for recovery per cent available. With this trend the number of factories reporting 100 per cent or over on available has steadily increased, a new maximum being reached this year with 29 factories so reporting in Table 4 and 19 in Table 5. The num-

TABLE NO. 4

APPARENT BOILING-HOUSE RECOVERY

Comparing per cent available sucrose in the syrup (calculated by formula) with per cent pol actually obtained.

Factory	Available*	Obtained	Recovery on Available	Molasses Produced on Theoretical†
H. C. & S. Co.	93.48	94.46	101.0	88.8
Oahu	91.83	93.62	101.9	89.2
Ewa	92.26	92.90	100.7	95.5
Waialua	91.06	91.57	100.6	85.0
Maui Agr.	92.56	94.03	101.6	85.9
Pioneer	92.16	92.06	99.9	94.4
Olaa	90.93	91.82	101.0	90.2
Lihue	90.76	92.40	101.8	90.7
Haw. Sug.	92.75	94.25	101.6	95.1
Honolulu	91.75	91.89	100.2	87.3
Kekaha	90.93	90.68	99.7	89.9
Haw. Agr.	91.17	91.14	100.0	94.8
Onomea	91.53	91.93	100.4	89.7
Hilo	90.30	91.12	100.9	92.9
Makee	87.97	88.08	100.1	88.3
Honokaa	88.33	89.05	100.8	90.1
Wailuku	91.63	92.38	100.8	92.5
McBryde	90.94	91.95	101.1	93.6
Hakalau	91.83	92.70	100.9	92.7
Laupahoehoe	92.71	91.90	99.1	87.5
Kahuku	90.40	93.39	103.3	94.1
Koloa	91.33	92.18	100.9	93.7
Waiakea	90.00	90.96	101.1	87.8
Pepeekeo	91.44	92.13	100.8	94.1
Hamakua	91.96	92.39	100.5	93.6
Paauhau	89.67	89.77	100.1	90.3
Hutchinson	90.30	91.68	101.5	90.0
Kohala (Hawi)	88.26	88.27	100.0	74.8
Honomu	91.71	92.57	100.9	93.4
Kohala	90.72	89.99	99.2	91.4
Kaiwiki	90.67	88.81	97.9	100.6
Waimanalo	88.07	89.48	101.6	88.0
Kilauea	84.73	82.84	97.8	74.5
Waianae	91.07	90.25	99.1	85.8
Kaeleku	87.70	86.10	98.2	...
Union Mill	87.91	87.43	99.5	87.7
Niulii	85.06	88.79	104.4	78.8
Waimea	91.25	88.70	97.2	...
Olowalu	89.55	89.74	100.2	97.0

* In order to calculate the available sucrose it is necessary to estimate the gravity purity of the syrup and sugar. Data from factories determining both apparent and gravity purities indicate that the average correction necessary is the addition of 0.8 to the apparent purity of the syrup and 0.3 to the apparent purity of the sugar. When moisture in sugar has not been reported, the moisture corresponding to 0.25 deterioration factor has been used. 38 has been used when the gravity purity of the molasses has not been reported.

† Gravity solids in syrup, less solids accounted for in commercial sugar considered as theoretical gravity solids in final molasses.

TABLE NO. 5

TRUE BOILING-HOUSE RECOVERY

Comparing per cent sucrose available and recovered

Factory	Available	Obtained	% Recovery on Available	Molasses Produced on Theoretical*
H. C. & S. Co.	93.34	94.00	100.7	84.8
Oahu	92.03	92.48	100.5	86.1
Ewa	92.51	91.94	99.4	97.2
Waialua	91.09	90.49	99.3	84.8
Maui Agr.	92.53	93.63	101.2	82.7
Pioneer	92.18	91.14	98.9	96.8
Olaa	90.82	91.15	100.4	87.3
Lihue	90.80	91.33	100.6	85.9
Haw. Sug	92.77	93.25	100.5	90.7
Honolulu	91.83	91.05	99.2	90.7
Kekaha	90.87	90.09	99.1	91.8
Haw. Agr.	91.26	90.35	99.0	97.8
Onomea	91.53	91.53	100.0	90.4
Hilo	89.88	90.98	101.2	88.1
Makee	88.23	86.90	98.5	90.6
Honokaa	88.44	88.50	100.1	89.8
Wailuku	91.64	91.62	100.0	91.1
McBryde	91.09	90.90	99.8	93.2
Hakalau	91.86	92.24	100.4	91.5
Laupahoehoe	92.67	91.26	98.5	92.8
Kahuku	90.76	92.05	101.4	88.7
Koloa	91.31	91.41	100.1	91.8
Waiakea	90.12	89.92	99.8	86.8
Pepeekeo	91.42	91.84	100.5	93.7
Hamakua	91.80	91.54	99.7	91.7
Paauhau	89.43	89.74	100.3	89.6
Hutchinson	90.39	90.89	100.6	88.0
Honomu	91.62	91.98	100.4	90.9
Kohala	90.81	89.42	98.5	96.7
Kaiwiki	90.27	88.78	98.3	107.1
Waimanalo	88.11	88.93	100.9	85.6
Kilauea	84.53	82.21	97.3	77.1
Waianae	91.32	89.18	97.7	92.2
Union Mill	87.98	85.71	97.4	89.8
Olowalu	89.30	89.49	100.2	96.0

* Calculated by S. J. M. formula.

TABLE NO. 6

GRAVITY SOLIDS AND SUCROSE BALANCES

Factory	GRAVITY SOLIDS PER 100 GRAVITY SOLIDS IN MIXED JUICE				SUCROSE PER 100 SUCROSE IN MIXED JUICE			
	Filter Cake	Commercial Sugar	Final Molasses	Undetermined	Filter Cake	Commercial Sugar	Final Molasses	Undetermined
H. C. & S. Co.	4.8	80.5	13.1	1.6	0.58	93.45	5.65	0.32
Oahu	4.7	76.8	16.3	2.2	0.29	92.21	6.86	0.64
Ewa	7.5	74.1	17.5	0.9	0.56	91.43	7.28	0.73
Waialua	3.0	76.4	17.1	3.5	0.16	90.35	7.56	1.93
Maui Agr.	..	82.5	15.0	2.5	...	93.63	6.18	0.19
Pioneer	4.7	75.7	18.2	1.4	0.25	90.91	7.57	1.27
Olaa	4.7	76.4	16.8	2.1	0.57	90.63	8.01	0.79
Lihue	5.2	74.9	17.6	2.3	0.79	90.61	7.90	0.70
Haw. Sug.	2.9	79.4	16.4	1.3	0.12	93.14	6.56	0.18
Honolulu	4.8	76.0	16.9	2.3	0.27	90.80	7.41	1.52
Kekaha	3.9	75.9	18.0	2.2	0.41	89.72	8.38	1.49
Haw. Agr.	2.8	76.6	19.5	1.1	0.28	90.10	8.55	1.07
Onomea	4.2	76.9	17.1	1.8	0.11	91.43	7.66	0.80
Hilo	4.9	74.4	19.1	1.6	0.25	90.75	8.92	0.08
Makee	4.7	69.7	22.3	3.3	0.49	86.47	10.66	2.38
Honokaa	6.3	69.9	21.6	2.2	0.72	87.86	10.38	1.04
Wailuku	5.4	76.6	16.5	1.5	0.53	91.13	7.62	0.72
McBryde	2.6	75.6	20.2	1.6	0.20	90.73	8.30	0.77
Hakalau	4.6	76.9	17.2	1.3	0.17	92.08	7.45	0.30
Laupahoehoe	3.0	78.0	16.5	2.5	0.14	91.13	6.80	1.93
Kahuku	4.8	73.7	20.0	1.5	0.23	91.84	8.20	—0.27
Koloa	5.4	74.0	19.1	1.5	0.63	90.83	7.98	0.56
Waiakea	4.5	73.6	19.0	2.9	0.55	89.43	8.58	1.44
Pepeekeo	5.5	75.0	18.6	0.9	0.27	91.59	8.04	0.10
Hamakua	..	79.3	19.4	1.3	...	91.54	7.52	0.94
Paauhau	4.8	73.8	19.5	1.9	0.54	89.26	9.47	0.73
Hutchinson	6.9	72.0	18.9	2.2	0.21	90.70	8.46	0.63
Honomu	6.7	74.7	17.2	1.4	0.21	91.79	7.62	0.38
Kohala	3.7	75.2	19.4	1.7	0.42	89.04	8.89	1.65
Kaiwiki	3.9	75.2	21.1	—0.2	0.45	83.38	10.42	0.75
Waimanalo	5.4	69.9	21.8	2.9	0.56	88.43	10.18	0.83
Kilauea	5.0	64.0	22.9	8.1	1.76	80.76	11.93	5.55
Waianae	3.8	73.9	19.0	3.3	0.30	88.91	8.00	2.79
Union Mill	5.9	70.7	19.5	3.9	0.70	85.11	10.80	3.39
Olowalu	7.6	70.8	21.0	0.6	0.48	89.06	10.27	0.19

TABLE NO. 7 SUCROSE DATA

Factory	Cane Sucrose*	MIXED JUICE		SYRUP		SUGAR		Undetermined Loss per 100 Sucrose* in cane
		Sucrose	Gravity Purity	Gravity Purity	Increase in Purity	Sucrose	Sucrose per 100 Sucrose* in cane	
H. C. & S. Co.	15.03	11.93	88.6†	88.6	0	98.10	91.54	0.31
Oahu	13.52	11.68	85.65	86.12	0.47	98.47	90.62	0.63
Ewa	13.22	11.22	83.98	86.23	2.25	98.41	89.94	0.71
Waialua	13.88	12.12	85.7	86.0	0.3	98.38	88.09	1.89
Maui Agr.	14.88	12.63	86.74†	87.0	0.26	97.92	91.68	0.19
Pioneer	13.93	12.27	84.62	85.9	1.28	98.02	88.95	1.24
Olaa	12.39	11.20	85.6	86.7	1.1	97.95	87.91	0.77
Lihue	12.09	11.10	83.8	85.2	1.4	97.75	87.81	0.68
Haw. Sug.	14.42	12.35	85.41	86.62	1.21	98.32	91.37	0.17
Honolulu	14.34	12.10	86.14	87.7	1.56	100.0	88.89	1.49
Kekaha	13.75	12.57	85.28	86.3	1.02	97.94	87.08	1.44
Haw. Agr.	11.77	10.88	85.33	85.92	0.59	98.15	87.53	1.04
Onomea	11.41	9.92	84.65	86.33	1.68	97.93	89.83	0.79
Hilo	11.24	10.07	83.57	84.52	0.95	97.69	88.77	0.08
Makee	11.67	10.31	82.1	82.88	0.78	97.89	82.97	2.28
Honokaa	9.72	9.86	81.22	83.00	1.78	97.87	83.02	0.99
Wailuku	13.62	11.01	85.7	87.2	1.5	98.12	89.74	0.71
McBryde	12.43	10.58	83.05	84.16	1.11	98.04	88.73	0.75
Hakalau	11.31	9.40	84.27	85.50	1.23	97.00	90.71	0.29
Laupahoehoe	12.10	10.43	86.52	86.96	0.44	98.29	88.30	1.88
Kahuku	11.60	10.32	81.74	83.03	1.29	98.36	89.90	—0.26
Koloa	11.89	10.37	82.76	84.44	1.16	98.27	88.30	0.55
Waiakea	11.98	10.59	83.30	84.39	1.09	98.00	85.97	1.39
Pepeekeo	11.60	10.38	83.14	85.41	2.27	98.38	89.36	0.10
Hamakua	11.82	11.21	85.64†	85.08	—0.56	98.42	88.72	0.91
Paauhau	11.24	9.73	83.66	85.03	1.37	97.73	87.19	0.72
Hutchinson	12.25	10.12	81.36	83.26	1.90	97.12	88.42	0.61
Honomu	11.22	9.89	84.10	85.95	1.85	98.26	88.61	0.36
Kohala	12.77	11.18	84.95	85.95	1.00	97.97	86.71	1.61
Kaiwiki	12.82	11.90	85.78	86.86	1.08	97.87	84.99	0.72
Waimanalo	11.93	9.95	79.98	81.32	1.34	97.16	87.20	0.81
Kilauea	10.96	10.34	79.72	80.56	0.84	97.76	76.90	5.29
Waianae	13.37	11.49	83.6	84.7	1.1	97.80	86.79	2.72
Union Mill	12.26	11.76	85.16	85.87	0.71	97.05	80.21	3.20
Olowalu	13.51	10.57	81.62	84.08	2.46	97.57	87.42	0.19
‡True Average 1931	12.75	11.17	84.74	85.78	1.04	98.05	88.61	0.89
" " 1930	12.67	11.08	85.35	86.49	1.14	98.05	88.90	0.89
" " 1929	13.08	11.44	85.58	86.60	1.02	98.00	88.75	1.05
" " 1928	12.69	11.22	85.15	86.23	1.08	97.86	88.49	1.21
" " 1927	12.46	11.01	84.53	85.86	1.33	97.79	87.96	1.13
" " 1926	13.35	11.68	85.38	86.66	1.28	97.67	88.41	1.20

* Pol in bagasse and press cake has been assumed to be the same as sucrose in calculating sucrose in cane.
‡ Clarified juice. † Refinery data from Honolulu not included in average.

ber of factories reporting excessively high recoveries on available, however, has not increased. We do not know just how much the calculated figure for available is too low, and no doubt there is some variation under conditions at different factories. However, if we arbitrarily place the limit for accurate control figures at 102 per cent recovery on available in Table 4 and 101 per cent in Table 5, we find two instances in Table 4, and three in Table 5, where recoveries on available are above these limits.

The amount of molasses accounted for is 89.0 per cent of the theoretical as calculated in Table 4 and 90.6 per cent of the theoretical as calculated in Table 5. Yearly averages for molasses per cent theoretical have varied but slightly from 90 per cent ever since these figures have been compiled. It is probable that we can accept this figure as approximately the amount of molasses that should be produced under average Hawaiian conditions. Assuming that a range of 5 points on each side of 90 per cent should include reasonably accurate figures, we find that in Table 4 two factories are above and three below this range, against one above and two below last year. In Table 5, six factories are above and four below, against four above and two below last year. It thus seems that molasses data are not quite as consistent as last year.

Table 6 contains gravity solids and sucrose balances for the 35 factories reporting sucrose data. But one factory has reported a negative undetermined loss of sucrose, against two last year. This factory also reported in excess of 101 per cent recovery on available in Table 5. A negative undetermined loss of solids has been reported from one factory.

Table 7 is a compilation of sucrose data with averages for the past six seasons. These data represent 97.3 per cent of the crop.

The average for undetermined loss in Table 7 enables us to correct the undetermined loss figure in the large table. This figure is too low, principally because sucrose in molasses is subtracted from pol entering the process. The undetermined loss in Table 7 is .89; the undetermined loss for the same factories on a pol basis is .07 and the difference between these figures is .82. The average for undetermined loss in the large table is .17. Adding .82 to this fiugre gives a corrected average for undetermined loss in the large table of .99.

Milling

Milling loss has been reduced to a lower point than in any previous season. Although slightly better extractions and extraction ratios were attained in 1920 and 1921, on the basis of milling loss we may conclude that milling has been better than in any previous season. The figure used as a standard for comparison in Java, "Undiluted Juice in Bagasse per cent Fiber," also indicates that milling has been better than in any previous year. Averages for bagasse moisture and bagasse pol are also new records.

It has been more difficult to attain a high quality of work than in 1920 and 1921 when the high point in extraction was reached. Tonnage and tonnage fiber ratios are now approximately one-third higher. Operating at higher capacity has limited the amount of water that can be applied and this is now almost a fifth less

than in those years. Also, cane pol is from .5 to 1.0 lower. On the other hand, carrying heavier pressure has been facilitated by strengthening equipment when replacements have been made and in some instances by new installations. The average pressure reported has increased almost 10 per cent. In general, attaining the present quality of work in spite of adverse factors may be attributed to careful attention to details which has resulted in more effective application of the pressure carried and more effective utilization of the water that can be applied.

In comparison with last year, the average extraction has increased .08 and the average milling loss has decreased .04. Moisture in bagasse has decreased .42 and pol in bagasse has decreased .01. Changes in grinding rate, tonnage fiber ratio, pressure on rollers and imbibition have been small. The average grinding rate has increased for the tenth successive year, the increase being from 51.79 to 52.01 tons. Tonnage fiber ratio is practically unchanged. Pressure per foot of top roller has decreased from 70.6 to 70.3 tons. Imbibition water has decreased from 33.26 to 33.19.

Although extraction has been higher and first expressed juice purity lower, the purity difference between first expressed and mixed juice (Table 3) has decreased from 2.95 to 2.89. The difference is smaller this year than in any season except 1929 when it was reduced to 2.80. While this purity difference is influenced by a number of factors, impurities extracted from field trash and losses of sucrose through bacterial action in mills are probably the principal factors influencing these averages. But little reliable information on changes in the amount of field trash is available so we cannot evaluate the influence of this factor. We do know, however, that much attention has been given to mill sanitation. Usually mills are now kept well washed down. Many pumps for the return of unstrained mill juices have been installed and the corresponding juice screens removed, and in a number of instances, juice pans, etc., have been sheathed with copper. Without doubt, the result of these efforts to reduce losses through better mill sanitation is reflected in the lower present day figures for purity differences between first expressed and mixed juice.

The purity difference between first expressed and last expressed juice has been reduced from 18.42 to 18.23.

A new record has been made in the number of factories reporting under 2.0 milling loss, nine so reporting against eight last year. Nine factories have reported over 98 extraction, a reduction of one from the previous record number of last year.

No new records have been made at individual factories in extraction, extraction ratio or milling loss.

Factories are arranged in the order of their milling loss in Table 8. Waimanalo and Hakalau are in first and second place respectively for the fourth successive year.

Adidtional milling equipment has been installed at Waialua and Honokaa. In each instance another unit has been added, converting these mills to a crusher and 15 rollers. The loss in bagasse has been reduced by slightly less than 30 per cent at each of these factories.

TABLE NO. 8—MILLING RESULTS

Showing the rank of the factories on the basis of milling loss.

Rank	1930 Rank	Factory	Milling Loss	Extraction Ratio	Extraction	Imbibition % Cane	Tonnage Ratio	Tonnage Fiber Ratio*
1	1	Waimanalo	1.25	10.6	98.59	39.57	1.90	25.3
2	2	Hakalau	1.43	12.8	98.49	38.56	1.71	20.2
3	4	Onomea	1.67	14.7	98.23	34.08	2.23	26.7
4	8	Wailuku	1.74	13.0	98.46	41.30	1.28	15.2
5	3	Honomu	1.77	16.1	98.08	32.42	1.61	19.2
6	5	Ewa	1.78	13.7	98.34	37.28	1.64	19.9
7	6	Olowalu	1.84	13.7	98.14	47.02	1.45	19.5
8	7	Hilo	1.89	16.9	97.80	32.18	1.97	25.6
9	12	Oahu	1.99	15.0	98.25	33.51	1.96	22.9
10	15	Paauhau	2.03	18.1	97.67	34.80	1.12	14.4
11	13	Kahuku	2.06	18.1	97.86	29.29	1.64	19.4
12	19	McBryde	2.08	17.0	97.76	37.37	1.56	20.6
13	10	Haw. Sug.	2.14	15.0	98.08	35.91	1.86	23.8
14	14	Pepeekeo	2.19	19.0	97.55	28.17	1.81	23.3
15	9	Pioneer	2.26	16.5	97.81	35.01	2.36	31.4
16	16	Kohala (Hawi)	2.32	19.0	97.59	26.50	2.13	27.0
17	17	Maui Agr.	2.36	15.9	97.91	38.64	1.83	24.0
18	11	H. C. & S. Co.	2.37	15.6	97.93	44.92	1.60	21.2
19	22	Hutchinson	2.42	20.0	97.46	39.43	1.82	23.1
20	20	Koloa	2.54	21.7	97.19	33.89	1.51	19.5
21	18	Waimea	2.56	19.1	97.66	33.04	1.68	20.5
22	28	Honolulu	2.60	18.4	97.87	35.47	1.38	16.0
23	21	Waianae	2.82	21.4	97.56	32.34	1.70	19.4
24	32	Waialua	2.82	20.6	97.47	34.50	2.54	31.2
25	25	Haw. Agr.	2.85	24.4	97.12	26.54	2.04	24.1
26	35	Hamakua	2.86	24.5	96.88	24.49	1.51	19.2
27	24	Lihue	2.93	24.7	96.86	28.20	2.41	30.6
28	33	Olaa	2.97	24.2	96.97	30.30	2.45	30.8
29	23	Kohala	3.07	24.4	97.36	30.20	1.66	18.0
30	27	Laupahoehoe	3.08	25.8	96.87	33.13	1.85	22.5
31	26	Kekaha	3.29	24.2	97.02	27.97	2.31	28.5
32	34	Waiakea	3.60	30.5	96.08	32.32	1.73	22.2
33	29	Kilauea	3.77	34.8	95.18	26.64	1.69	23.4
34	30	Makee	3.78	33.0	95.88	30.72	2.32	29.0
35	31	Kaiwiki	3.91	30.7	96.13	25.78	1.68	21.2
36	38	Honokaa	4.05	42.1	94.44	19.25	1.87	24.7
37	36	Kaeleku	4.78	40.8	93.95	35.56	1.77	26.3
38	37	Union Mill	5.04	41.9	94.12	23.58	1.72	24.1
39	39	Niulii	5.78	55.0	92.23	25.11	1.91	26.9

* Tonnage ratio multiplied by per cent fiber in cane.

Boiling House Work

This year it has been necessary to handle lower purity juices in the boiling house, the mixed juice purity being .54 lower than last season, and lower than in any preceding season except 1927 and 1921.

Clarification has been less satisfactory than last season, but better results have been secured in filtration. The low grade work has been better than in any previous year and the deterioration factor also has been reduced to a lower point than ever before.

Clarification:

Both the increase in purity from mixed juice to syrup and the turbidity of the clarified juice are less satisfactory than last year. The increase in purity (Table 3) has dropped from 1.44 to 1.36. The turbidity has dropped from 3.45 to 3.41. Slightly more lime was used and the average pH of the hot limed juice was slightly higher.

Filtration:

The following refers to data in Table 3. Filtration losses have again been reduced. The cake pol is the lowest in ten years and the loss per cent pol in cane is the lowest in seven years. Filtration losses have been reduced at 70 per cent of the larger factories.

Following the trend of recent years, the weight of cake per cent cane has increased. The amount this year, 2.99 per cent, is the highest on record. Cake pol has been reduced from 1.82 to 1.65. This decrease has been sufficient to offset the increase of .03 in weight of cake and to reduce the loss in filter cake per cent pol in cane from .44 to .40. Loss in filter cake reached a maximum of .55 in 1928. Since that time it has been reduced each year.

This year an Oliver-Campbell filter was installed at Kekaha. This filter is of the vacuum drum type, covered with a perforated metal screen. Fine bagasse is added to the settlings as a filter aid. The filter was operated during the last two or three months of the season. The filter cake loss at Kekaha has been close to the average for the Islands in the last few years. When this filter was used, there was little difficulty in cutting this loss in half. Undoubtedly, the results can be improved with further experience. This type of filter has a large capacity and the operation is satisfactory. From present indications, it seems that there is now some prospect of putting the filtration of settlings on an economical and technically satisfactory basis. The first successful operation of a vacuum drum type of filter on settlings in a cane sugar factory was at Oahu in 1926. In the six years since that time, design and practice have developed to the extent that it now seems that a thoroughly satisfactory solution of the filtration problem is in sight.

Evaporation:

The average syrup density has decreased from 64.34 to 64.15. The latter figure, however, is higher than in any year except 1930.

Evaporator capacity has been increased at two factories, Hutchinson and Hawaiian Agricultural Co.

Commercial Sugar:

Pol has again increased slightly, bringing the average from 97.66 to 97.69. The average for the group of factories shipping to Crockett has increased .01; for the other factories the increase has been .12. Averages for the two groups are now 97.78 and 96.96 respectively.

Moisture has been reduced, bringing the deterioration factor to .231, a new record. The deterioration factor has been reduced each year since 1925.

The number of factories reporting average deterioration factors higher than .25 has been reduced from 6 to 3. In 1929 thirteen factories reported in excess of .25.

Low Grade Sugar:

Notwithstanding an improvement in final molasses purity which might be expected to influence the low grade sugar purity adversely, the average purity of the low grade sugar has not decreased. On the contrary there has been a slight improvement, from 75.66 to 75.69.

Final Molasses:

A new record has been made in final molasses purity, the average having been reduced from 36.69 to 36.32. The final molasses purity has been reduced in each year since 1926. Although the molasses purity has been reduced considerably, this improvement has not offset the influence of lower juice purities and both the quantity of molasses and the loss of sucrose in molasses have increased.

Factories are listed according to final molasses purity in the following table:

GRAVITY PURITY FINAL MOLASSES

32–33		35–36		38–39	
Kahuku	32.37	Hakalau	35.34	Kohala	38.10
		Honomu	35.63	Olowalu	38.15
33–34		Maui Agr.	35.74	Wailuku	38.35
Hamakua	33.21			Kekaha	38.72
Ewa	33.39	36-37			
Koloa	33.54	Waimanalo	36.05	39–40	
Haw. Sug.	33.61	Lihue	36.48		
McBryde	33.81	Waiakea	36.56	Kohala (Hawi)	39.13
		H. C. and S.	36.62	Kaeleku	39.33
34–35		Haw. Agr.	36.71	Paauhau	39.56
		Honolulu	36.81	Olaa	39.6
Pioneer	34.24	Waialua	36.96		
Waianae	34.38			Over 40	
Oahu	34.62	37–38			
Hutchinson	34.69	Onomea	37.01	Kilauea	40.51
Laupahoehoe	34.76	Hilo	37.60	Kaiwiki	41.42
Pepeekeo	34.97	Honokaa	37.71	Niulii	42.39
		Makee	37.85	Union Mill	45.06

The first nine factories are lower in purity than last year and are also lower than in 1929. Twenty-four factories reduced molasses purity while 14 have reported increases. Factories that have reduced molasses purity 1.5 or more are

Waianae, Hawaiian Agricultural Co., Kaiwiki and Hawaiian Sugar Co. There are now only four factories reporting 40 purity or higher, compared with six last year and seven in 1929.

Kahuku is again in first place for the ninth successive year. The record for molasses purity, 31.81, was made at this factory in 1927.

Undetermined Loss:

The average for undetermined loss in the large table has increased from .14 to .17. With these figures corrected as indicated in the discussion of chemical control, the increase is from .98 to .99. This is the first year since 1925 that the undetermined loss average in the large table has not decreased. The undetermined loss on a sucrose basis, Table 7, is the same as last year, .98.

Recovery

Improvements in factory work, discussed in preceding sections, have not been sufficient to offset lower initial purity, and recoveries have decreased; the boiling house recovery from 91.77 to 91.54 and the total recovery from 89.33 to 89.17.

With the same quality of work as last year we would expect a decrease in total recovery of about .44 because of lower initial purity. The actual decrease has been but .16. The difference, .28, may be credited to a smaller decrease in purity from first expressed to mixed juice, higher extraction, a reduction in filter cake loss and lower molasses purity, these improvements being partially offset by a smaller increase in purity in clarification.

Calculations based on quality ratio indicate the same improvement in factory work as control data. After correcting quality ratios for fiber in cane and sugar pol, we find that in 1930 the recovery of sugar was 99.74 per cent of the recovery indicated by quality ratio. This year the recovery was 100.02 per cent, an improvement of .28, which may be credited to better factory work.

Comparison of Actual and Calculated Recoveries

These comparisons are in Table 9. Values assumed in calculating the theoretical recoveries are given in footnotes accompanying the table. As in the past few years no attempt has been made to designate probable inaccuracies in control data. It is possible to exceed 100 per cent recovery on available in either comparison even in the absence of control errors for reasons which have been discussed in previous Synopses.

The two comparisons are being continued in their present form until a better method for comparing factory work is devised. If allowance is made for factors which introduce discrepancies in comparisons of this kind, they give a fair idea of the work of a factory, provided there are no large errors in the control.

Table 10 containing the summary of losses is given in the usual form.

The calculations in this Synopsis have been made by Mr. Brodie, assisted by Mr. Ashton and others of this department.

TABLE NO. 9

COMPARISON OF ACTUAL AND THEORETICAL RECOVERIES

Rank	Factory	Recovery % Calculated Recovery *			Recovery % Recovery Indicated by "Sugar Ratio" †	
		Milling	Boiling House	Over All	Rank	Over All
1	Kahuku	97.86	105.94	103.97	1	103.04
2	Oahu	98.25	102.88	101.37	3	101.20
3	Haw. Sug.	98.08	103.01	101.27	2	101.48
4	Waimanalo	98.59	101.94	100.79	13	99.21
5	McBryde	97.76	102.71	100.71	5	100.69
6	Hutchinson	97.45	102.75	100.56	10	99.38
7	Maui Agr.	97.91	102.24	100.52	6	100.47
8	Hakalau	98.49	101.68	100.45	7	100.27
9	Ewa	98.34	101.80	100.39	4	100.81
10	Honomu	98.08	101.49	99.87	8	100.01
11	Koloa	97.19	102.14	99.71	14	99.08
12	Hamakua	96.88	102.33	99.65	19	98.66
13	Pepeekeo	97.55	101.59	99.27	12	99.22
14	Pioneer	97.81	100.96	99.08	16	98.87
15	Onomea	98.23	100.51	99.07	9	99.92
16	H. C. & S. Co.	97.93	100.74	98.92	11	99.37
17	Wailuku	98.46	99.95	98.68	15	99.01
18	Lihue	96.86	101.45	98.67	17	98.82
19	Hilo	97.80	100.62	98.64	21	98.08
20	Waialua	97.47	100.64	98.42	20	98.35
21	Honolulu	97.87	100.14	98.17	18	98.74
22	Waianae	97.56	100.23	98.02	22	97.95
23	Olowalu	98.14	99.42	97.86	26	97.24
24	Haw. Agr.	97.12	100.01	97.45	23	97.43
25	Waiakea	96.08	100.97	97.37	28	96.93
26	Laupahoehoe	96.87	99.98	97.11	24	97.28
27	Olaa	96.97	99.54	96.90	25	97.28
28	Kohala (Hawi)	97.59	98.73	96.71	30	96.29
29	Paauhau	97.67	98.62	96.57	31	95.52
30	Kekaha	97.02	98.81	96.33	29	96.85
31	Kohala	97.36	98.52	96.23	27	96.96
32	Makee	95.88	99.41	95.94	32	94.85
33	Honokaa	94.44	99.97	94.89	34	94.23
34	Waimea	97.66	96.42	94.44	33	94.57
35	Kaiwiki	96.13	96.00	92.59	35	93.30
36	Niulii	92.23	99.37	92.17	36	91.03
37	Kaeleku	93.95	95.94	90.55	38	90.01
38	Kilauea	95.18	93.99	89.98	39	88.92
39	Union Mill	94.12	95.19	89.90	37	90.08

* Factories are arranged in the order of the ratio of their recovery to that calculated on the basis of 100% extraction, 37.5 gravity purity molasses and no other losses.

† The basis of this calculation is 98 extraction, syrup purity one less than the apparent purity of the first expressed juice, sugar purity 98, gravity purity of molasses 33.33 and no other losses.

TABLE NO. 10

SUMMARY OF LOSSES

FACTORY	POUNDS POL PER TON OF CANE					POL PER 100 CANE					POL PER 100 POL OF CANE					Syrup Purity	FACTORY
	Bagasse	Filter Cake	Molasses	Undetermined	TOTAL	Bagasse	Filter Cake	Molasses	Undetermined	TOTAL	Bagasse	Filter Cake	Molasses	Undetermined	TOTAL		
H. C. & S. Co.	6.2	1.6	16.6	—0.6	23.8	0.31	0.08	0.83	—0.03	1.19	2.07	0.57	5.58	—0.19	8.03	87.99	H. C. & S. Co.
Oahu	4.6	0.8	18.2	—1.6	22.0	0.23	0.04	0.91	—0.08	1.10	1.75	0.29	6.84	—0.59	8.29	85.07	Oahu
Ewa	4.4	1.4	19.0	—0.8	24.0	0.22	0.07	0.95	—0.04	1.20	1.66	0.56	7.26	—0.31	9.17	84.94	Ewa
Waialua	7.0	0.4	20.4	2.0	29.8	0.35	0.02	1.02	0.10	1.49	2.53	0.16	7.48	0.72	10.89	85.1	Waialua
Maui Agr.	6.2	...	18.0	—0.8	23.4	0.31	...	0.90	—0.04	1.17	2.09	...	6.09	—0.24	7.94	86.27	Maui Agr.
Pioneer	6.0	0.6	20.6	0.8	28.0	0.30	0.03	1.03	0.04	1.40	2.19	0.24	7.50	0.25	10.18	85.09	Pioneer
Olaa	7.4	1.4	19.2	0.2	28.2	0.37	0.07	0.96	0.01	1.41	3.03	0.56	7.85	0.04	11.48	86.0	Olaa
Lihue	7.4	1.8	18.6	—1.2	26.6	0.37	0.09	0.93	—0.06	1.33	3.14	0.78	7.77	—0.47	11.22	84.3	Lihue
Haw. Sug.	5.4	0.4	18.6	—2.6	21.8	0.27	0.02	0.93	—0.13	1.09	1.92	0.12	6.53	—0.90	7.67	85.77	Haw. Sug.
Honolulu	6.0	0.8	20.8	...	...	0.30	0.04	1.04	...	...	2.13	0.27	7.31	....	....	86.8	Honolulu
Kekaha	8.2	1.0	22.4	2.2	33.8	0.41	0.05	1.12	0.11	1.69	2.98	0.40	8.22	0.79	12.39	85.48	Kekaha
Haw. Agr.	6.8	0.6	19.6	0.4	27.4	0.34	0.03	0.98	0.02	1.37	2.88	0.28	8.39	0.19	11.74	85.12	Haw. Agr.
Onomea	4.0	0.2	17.2	0.8	22.2	0.20	0.01	0.86	0.04	1.11	1.77	0.11	7.57	0.35	9.80	85.57	Onomea
Hilo	5.0	0.6	19.6	—0.2	25.0	0.25	0.03	0.98	—0.01	1.25	2.20	0.24	8.78	—0.12	11.10	84.08	Hilo
Makee	9.4	1.2	23.8	2.2	36.6	0.47	0.06	1.19	0.11	1.83	4.12	0.48	10.40	0.98	15.98	81.7	Makee
Honokaa	10.8	1.2	19.0	0.8	31.8	0.54	0.06	0.95	0.04	1.59	5.56	0.68	9.90	0.37	16.51	82.03	Honokaa
Wailuku	4.2	1.4	20.4	—0.4	25.6	0.21	0.07	1.02	—0.02	1.28	1.54	0.53	7.61	—0.14	9.54	86.2	Wailuku
McBryde	5.4	0.4	20.2	—1.0	25.0	0.27	0.02	1.01	—0.05	1.25	2.24	0.19	8.23	—0.37	10.29	83.22	McBryde
Hakalau	3.4	0.4	16.6	—0.6	19.8	0.17	0.02	0.83	—0.03	0.99	1.51	0.17	7.42	—0.24	8.86	84.49	Hakalau
Laupahoehoe	7.6	0.4	16.0	2.8	26.8	0.38	0.02	0.80	0.14	1.34	3.13	0.14	6.64	1.19	11.10	86.32	Laupahoehoe
Kahuku	4.8	0.6	18.6	—4.0	20.0	0.24	0.03	0.93	—0.20	1.00	2.14	0.23	8.17	—1.72	8.82	81.68	Kahuku
Koloa	6.6	1.4	18.4	—0.6	25.8	0.33	0.07	0.92	—0.03	1.29	2.81	0.61	7.85	—0.30	10.97	83.70	Koloa
Waiakea	9.2	1.2	19.8	0.6	30.8	0.46	0.06	0.99	0.03	1.54	3.92	0.54	8.37	0.27	13.10	83.38	Waiakea
Pepeekeo	5.6	0.6	18.2	—0.6	23.8	0.28	0.03	0.91	—0.03	1.19	2.45	0.27	7.89	—0.24	10.37	84.62	Pepeekeo
Hamakua	7.2	...	17.2	0.0	24.4	0.36	...	0.86	0.00	1.22	3.12	...	7.39	—0.01	10.50	84.43	Hamakua
Paauhau	5.2	1.2	20.8	1.4	28.6	0.26	0.06	1.04	0.07	1.43	2.33	0.53	9.33	0.61	12.80	84.14	Paauhau
Hutchinson	6.2	0.4	20.2	—0.6	26.2	0.31	0.02	1.01	—0.03	1.31	2.54	0.21	8.34	—0.25	10.84	82.37	Hutchinson
Kohala (Hawi)	5.8	1.0	21.4	6.4	34.6	0.29	0.05	1.07	0.32	1.73	2.41	0.38	8.78	2.62	14.19	82.75	Kohala (Hawi)
Honomu	4.2	0.4	16.8	—0.6	20.8	0.21	0.02	0.84	—0.03	1.04	1.92	0.20	7.55	—0.27	9.40	85.24	Honomu
Kohala	6.6	1.0	22.2	2.4	32.2	0.33	0.05	1.11	0.12	1.61	2.64	0.41	8.75	0.96	12.76	85.01	Kohala
Kaiwiki	9.8	1.2	25.6	1.6	38.2	0.49	0.06	1.28	0.08	1.91	3.87	0.43	10.07	0.64	15.01	86.34	Kaiwiki
Waimanalo	3.4	1.2	24.0	0.4	29.0	0.17	0.06	1.20	0.02	1.45	1.41	0.55	10.16	0.15	12.27	80.33	Waimanalo
Kilauea	10.4	3.6	24.8	10.0	48.8	0.52	0.18	1.24	0.50	2.44	4.82	1.69	11.46	4.59	22.56	80.0	Kilauea
Waianae	6.4	0.8	21.0	4.0	32.2	0.32	0.04	1.05	0.20	1.61	2.44	0.30	7.95	1.54	12.23	83.37	Waianae
Kaeleku	14.2	2.8	...	30.2	47.2	0.71	0.14	...	1.51	2.36	6.05	1.18	....	12.90	20.13	82.06	Kaeleku
Union Mill	14.2	1.6	25.0	3.2	44.0	0.71	0.08	1.25	0.16	2.20	5.88	0.68	10.38	1.37	18.31	85.11	Union Mill
Niulii	16.4	3.2	20.8	0.6	41.0	0.82	0.16	1.04	0.03	2.05	7.77	1.56	9.88	0.28	19.49	81.46	Niulii
Waimea	6.2	1.6	...	29.2	37.0	0.31	0.08	...	1.46	1.85	2.34	0.59	....	10.97	13.90	85.39	Waimea
Olowalu	5.0	1.2	27.2	—0.4	33.0	0.25	0.06	1.36	—0.02	1.65	1.86	0.46	10.14	—0.11	12.35	83.54	Olowalu

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 17 TO DECEMBER 15, 1931

Date	Per Pound	Per Ton	Remarks
Sept. 17, 1931	3.40¢	$68.00	Cubas.
" 22	3.39	67.80	Cubas, 3.38, 3.40.
" 23	3.4217	68.43	Cubas, 3.415, 3.42; Porto Ricos, 3.43.
" 28	3.40	68.00	Cubas.
Oct. 2	3.43375	68.68	Philippines, 3.415; Cubas, 3.43, 3.44, 3.45.
" 5	3.45	69.00	Cubas.
" 6	3.44	68.80	Cubas, Porto Ricos.
" 7	3.45	69.00	Porto Ricos.
" 8	3.435	68.70	Cubas.
" 15	3.40	68.00	Cubas.
" 19	3.42	68.40	Cubas, Porto Ricos.
" 20	3.40	68.00	Cubas, 3.42, 3.40, 3.38.
" 22	3.36	67.20	Cubas.
" 29	3.42	68.40	Cubas.
" 30	3.40	68.00	Cubas.
Nov. 4	3.42	68.40	Cubas, Porto Ricos.
" 6	3.385	67.70	Cubas, 3.39, 3.38.
" 13	3.395	67.90	Cubas, 3.40, 3.39.
" 14	3.38	67.60	Cubas.
" 17	3.37	67.40	Cubas.
" 19	3.36	67.20	Philippines.
" 21	3.30	66.00	Porto Ricos.
" 25	3.28	65.60	Cubas.
" 27	3.25	65.00	Cubas.
" 30	3.21	64.20	Porto Ricos.
Dec. 1	3.20	64.00	Cubas.
" 7	3.15	63.00	Cubas.
" 9	3.125	62.50	Cubas, 3.13, 3.12.
" 10	3.105	62.10	Cubas, 3.11, 3.10.
" 11	3.10	62.00	Cubas.
" 15	3.12	62.40	Cubas.

ANNUAL SYNOPSIS OF MILL DATA—SHOWING RESULTS FROM 39 HAWAIIAN FACTORIES FOR CROP OF 1931

Factory	Factory No.	Milling Plant (Sizes in Inches)	CANE: Pol	CANE: % Fiber	CANE: Tons per ton commercial sugar	CANE: Gross weight of cane	BAGASSE: Tonnage mills	BAGASSE: Tonnage fiber ratio	FIRST EXPRESSED JUICE: Pol	FIRST EXPRESSED JUICE: % Moisture	FIRST EXPRESSED JUICE: Purity	FIRST EXPRESSED JUICE: Pol of cane ÷ 100 Pol	Factory No.	MIXED JUICE: Brix	MIXED JUICE: Pol	MIXED JUICE: Purity	MIXED JUICE: pH Lead Subacetate	MIXED JUICE: Weight per 100 cane	MIXED JUICE: Pol per 100 cane	MIXED JUICE: Pol per 100 pol. in cane "Extraction"	Extraction Ratio	LAST EXPRESSED JUICE: Pol	LAST EXPRESSED JUICE: Turbidity Coulometers	IMBIBITION WATER: Weight per 100 cane	IMBIBITION WATER: Dilution % Mixed Juice	Factory No.	CLARIFIED JUICE: Purity	CLARIFIED JUICE: pH	CLARIFIED JUICE: Turbidity Coulometers	SYRUP: Purity	SYRUP: Increase in Purity	SYRUP: pH	FILTER CAKE: Pol	FILTER CAKE: Weight per 100 cane	FILTER CAKE: Pol per 100 cane	FILTER CAKE: Pol per 100 pol. of cane	LIME USED Pounds available CaO per ton cane: In Juice	LIME USED: In Settlings	LIME USED: Total	COMMERCIAL SUGAR: Test	COMMERCIAL SUGAR: % Moisture	COMMERCIAL SUGAR: Deterioration Factor	COMMERCIAL SUGAR: Weight per 100 cane	COMMERCIAL SUGAR: Pol per 100 cane	COMMERCIAL SUGAR: Pol per 100 pol of cane	COMMERCIAL SUGAR: Pol per 100 pol. in cane "Extraction"	COMMERCIAL SUGAR: Total weight lost per 100 cane	COMMERCIAL SUGAR: Purity low grade sugar	Factory No.	FINAL MOLASSES: Weight per 100 cane	FINAL MOLASSES: Sucrose per 100 pol of cane	FINAL MOLASSES: Sucrose per 100 pol. in cane "Extraction"	FINAL MOLASSES: Gravity solids	FINAL MOLASSES: Gravity purity	UNDETERMINED LOSSES: Pol per 100 cane	UNDETERMINED LOSSES: Pol per 100 pol of cane	Factory
H. C. & S. Co.**	6	K(4),2RC78(2),S72(2),12RM78(2)..	14.91	12.98	7.13	5191	1.60	21.2	1.43	37.67	60.34	0.31	2.07	2.37	21.52	6	13.46	11.53	87.90	....	133.39	14.60	97.93	15.6	2.28	71.91	44.92	48.51	6	87.90	7.10	3.49	64.65	87.99	0.09	7.09	2.69	3.16	0.08	0.57	....	....	....	1.44	97.80	0.50	0.23	14.62	13.71	91.97	94.01	77	22.4	6	2.56	0.62	2.58	5.51	88.74	0.06	0.19	0.67	6	H. C. & S. Co.**
Oahu	20	K(2),2RC78(2),S72(2),12RM78(2)..	13.33	11.68	8.04	6031	1.96	22.9	1.18	39.01	59.20	0.31	1.75	1.99	19.73	20	12.33	10.15	87.21	8.09	117.73	13.10	98.35	15.0	2.53	71.91	44.92	48.51	20	85.03	7.31	4.69	67.66	87.99	0.09	7.09	2.91	2.99	0.04	0.29	0.92	0.58	1.50	97.23	0.78	0.24	12.21	11.87	97.21	98.56	78	24.5	20	2.56	0.62	2.58	5.51	88.74	0.06	0.19	0.67	20	Oahu
Ewa	5	2RC78,2RM78	13.03	12.12	8.25	1204	1.04	19.9	1.01	41.77	56.66	0.22	1.66	1.78	21.39	5	18.40	15.83	86.03	82.3	13.36	11.05	82.71	8.41	115.89	12.81	98.34	13.7	1.17	64.62	37.28	34.73	5	84.56	7.41	4.24	64.87	84.94	2.23	7.17	2.29	3.26	0.07	0.56	1.10	0.24	1.34	97.23	0.74	0.24	12.08	11.75	97.33	98.56	78	24.1	5	2.56	0.62	2.58	5.51	88.74	0.06	0.19	0.67	5	Ewa
Waialua	17	3RC78,2RM78	13.67	12.28	8.04	10824	2.54	21.2	1.52	43.97	63.86	0.35	2.33	2.82	23.80	17	14.14	12.07	85.37	82.0	14.14	12.07	85.37	8.60	119.74	14.77	97.47	15.6	2.39	70.51	41.77	45.91	17	85.77	7.50	3.96	65.53	85.1	0.7	7.35	2.39	2.78	0.06	0.49	1.37	0.32	1.69	97.59	0.46	0.23	12.43	12.13	97.59	98.56	78	24.82	17	2.56	0.62	2.58	5.51	88.74	0.06	0.19	0.67	17	Waialua
Maui Agr.**	21	K(4),3RC66(2),12RM66(2)..	14.78	13.11	7.18	4051	1.83	24.0	1.33	41.46	56.41	0.31	2.09	2.36	23.24	21	14.50	12.54	86.13	....	115.40	14.47	97.91	15.9	1.77	63.21	38.64	35.92	21	86.13	6.86	2.59	64.45	86.27	0.34	6.95	2.63	3.49	0.02	0.16	1.37	1.32	2.69	97.68	0.48	0.23	12.43	12.18	98.11	98.44	78	24.82	21	2.56	0.62	2.58	5.51	88.74	0.06	0.19	0.67	21	Maui Agr.**
Pioneer	10	K2RC78,2RM78	13.76	13.30	7.91	885	2.36	31.4	1.26	42.45	55.68	0.30	2.19	2.26	23.88	10	20.12	17.52	87.03	78.5	14.50	12.11	88.62	7.99	111.11	13.46	97.81	16.5	1.51	66.68	35.01	31.67	10	84.80	7.42	3.21	64.20	84.95	1.57	7.41	1.12	2.99	0.03	0.24	1.99	1.99	97.75	0.49	0.22	12.36	12.08	97.85	98.43	77	24.53	10	3.49	1.68	7.50	7.77	83.26	0.03	0.09	0.21	10	Pioneer
Olaa	26	2RC78,3RC72,2RM78	12.57	12.58	8.99	3257	2.45	33.8	1.27	42.45	58.83	0.32	2.45	2.58	23.87	26	17.45	14.91	85.44	79.9	13.24	10.93	82.55	7.63	105.32	11.53	98.68	24.7	1.29	70.1	30.30	27.27	26	86.1	7.8	3.8	64.35	86.0	1.4	7.6	1.96	3.48	0.07	0.56	1.32	0.32	1.64	97.61	0.61	0.26	13.12	12.86	98.02	98.43	78	25.68	26	3.49	1.68	7.50	7.77	83.26	0.03	0.09	0.21	26	Olaa
Libue	27	2RC78,3RC72,2RM78	11.91	12.70	9.21	4092	2.41	39.6	1.64	41.60	56.00	0.37	3.14	2.93	22.68	27	17.45	14.91	85.44	79.9	13.24	10.93	82.55	7.63	105.32	11.53	98.68	24.7	2.24	66.8	28.20	25.53	27	86.1	7.30	3.82	63.75	84.3	1.8	7.17	1.81	3.81	0.09	0.78	1.81	1.81	97.58	0.47	0.23	13.12	12.86	98.02	98.43	78	25.68	27	3.49	1.68	7.50	7.77	83.26	0.03	0.09	0.21	27	Libue
Haw. Sug.	16	2RC78,3RC72,2RM78	14.32	12.81	7.46	4033	1.86	23.8	1.28	38.34	59.84	0.27	1.92	2.14	21.40	16	19.22	16.80	87.41	84.6	14.46	12.18	84.23	8.0	114.51	13.95	98.08	15.0	2.22	70.25	35.91	31.60	16	85.26	7.2	3.3	64.15	85.23	1.27	7.43	1.85	3.41	0.08	0.72	1.55	0.34	1.89	97.58	0.47	0.23	12.13	11.84	97.64	98.43	78	24.16	16	3.49	1.68	7.50	7.77	83.26	0.03	0.09	0.21	16	Haw. Sug.
Honolulu††	13	2RC78,3RC72,2RM78	13.61	12.33	8.18	3.76	2.31	28.5	1.86	40.61	56.58	0.41	2.98	3.29	21.79	13	18.31	16.29	88.97	83.1	14.04	11.69	85.44	8.2	116.09	13.55	97.87	18.4	2.53	73.63	35.47	34.33	13	87.0	7.3	5.15	66.84	86.8	1.31	1.35	2.81	0.04	0.27	....	....	....	2914	83.3	13	3.09	1.04	7.31	7.47	91.29	36.81	....	....	....	13	Honolulu†
Haw. Agr.††	30	2RC78,3RC72,2RM78	11.66	11.79	9.52	331	2.04	34.1	1.57	42.76	55.04	0.34	2.88	2.85	21.41	30	16.46	14.28	86.78	....	12.75	10.77	84.47	8.30	105.14	11.32	97.12	24.4	1.53	71.43	26.54	25.26	30	85.17	7.60	....	66.54	85.12	0.65	7.60	1.17	2.74	0.03	0.28	1.03	1.83	98.09	0.44	0.24	12.49	12.29	98.25	....	....	....

FACTORY EQUIPMENT—INCLUDES IMPROVEMENTS INSTALLED FOR THE 1932 CROP

Data based on tons cane per hour rated capacity.

Factory	Factory No.	Capacity T. C. H.		MILLING PLANT (Sizes in Inches)	MILL ENGINES	BOILERS b Sq. Ft.		FURNACES			STACKS				GENERATORS			Factory No.	JUICE HEATERS Sq. Ft.			SETTLING TANKS Cu. Ft.		FILTERS Sq. Ft.		EVAPORATORS Sq. Ft.			PAN SUPPLY TANKS Cu. Ft.		VACUUM PANS					VACUUM PUMPS		CRYSTALLIZERS				MASSECUITE TANKS	CENTRIFUGALS Screen Area Sq. Ft.			Factory No.	Factory
		Rated capacity	Capacity at 2.0 tonnage ratio		Diameter x Stroke (No. of rollers in parentheses)	Water tube	Fire tube	Grate area sq. ft.	Tuyeres sq. ft.	Combustion volume cu. ft.	Dia. at top, ft.	Height, ft.	Dia. at top, ft.	Height, ft.	K. V. A.	K. W. used in Factory	K. W. used Outside		Mixed juice baffled	Mixed juice unbaffled	Clarified juice	Intermittent	Continuous	Plate and frame	Continuous, Oliver	Preevaporator	Triple	Quadruple	Syrup and Remelt	Molasses	Commercial Sugar		Low Grade		Total		Main Pumps cu. ft. per minute	Auxiliaries cu. ft. per minute	Without Coils	With Coils			Low Grade Cu. ft.	Commercial sugar	Low grade	Total		
																														Sq. ft.	Cu. ft.	Sq. ft.	Cu. ft.	Sq. ft.	Cu. ft.			Cu. ft.	Cu. ft.	Sq. ft. per Cu. ft. Capacity							
H. C. & S. Co.*	6	130	140.8	K(4),2RC78(2),S72(2),12RM78(2)	16x36(2),28x60(9),22x48(3)	61.3	351.7	3.3	....	127.4	12	180	12	180	14.4	9.6	....	6	17.8	34.0	...	....	117.5P	1.8K	...	40.4	....	285.2	46.0	39.0	44.2	43.0	32.6	40.0	76.8	83.0	44.1	....	295.4	....	....	....	1.78	6.44	8.22	6	H. C. & S. Co.*
Oahu*	20	145	140.8	K(2),2RC78(2),S72(2),12RM78(2)	24x48(5),30x60(9)	323.0	....	2.4	....	35.9	10	231	10	173	28.4	6.7	4.3	20	28.3	....	...	....	63.0d	....	8.3	37.9	....	200.0	23.7	39.4	26.2	25.5	19.9	18.4	46.1	43.9	35.6	35.3	29.0	146.2	.34	....	1.16	2.02	3.18	20	Oahu*
Ewa	5	95	98.6	K(2),2RC78,18RM78	20x50(11),30x54(9)	472.1	....	6.0	.04	69.3	7	137	8	150	36.2	4.4	17.0	5	23.6	....	...	106.3	....	91.0	6.3	63.2	....	310.5	46.9	18.0	29.3	31.7	21.1	20.9	50.4	52.6	15.9	9.5	75.8	170.5	.13	....	1.77	5.28	7.05	5	Ewa
Waialua	17	110	84.5	K(2),2RC78,15RM78	26x54(5),30x60(9),22x48(3)	316.1	....	7.2	....	....	12	175	....	....	31.8	5.5	18.2	17	17.3	6.0	...	76.1	....	83.8	....	54.5	....	208.2	20.7	41.4	36.3	38.2	23.9	15.7	60.2	53.9	36.3	....	163.6	....	....	....	1.52	2.67	4.19	17	Waialua
Maui Agr.*	21	110	100.8	K(4),3RC66(2),12RM66(2)	28x42(6),28x48(9)	352.8	....	....	....	....	10	120	....	....	52.7	7.3	12.7	21	35.0	....	12.4	....	94.6P	....	....	80.3	....	232.5	52.2	33.0	67.1	33.4	40.8	30.5	107.9	63.9	46.3	....	185.0	108.7	.17	....	1.14	2.83	3.97	21	Maui Agr.*
Pioneer	10	90	72.0	K,2RC72,S72,15RM72	16x36(2),26x42(6),28x54(9)	216.4	98.2	4.2	....	66.0	12	225	....	....	11.1	5.6	4.2	10	24.9	20.0	...	78.8	....	71.1	....	....	....	266.7V_3	47.5	45.7	45.4	43.3	34.8	28.9	80.2	72.2	45.9	....	222.8	....	....	458.0	1.86	4.65	6.51	10	Pioneer
Olaa	36	100	70.4	K,2RC78,S72,12RM78	18x42(2),26x48(3),28½x60(9)	76.8	203.2	2.6	.05	53.8	9¼	180	....	....	12.5	6.0	....	36	...	25.1	....	71.9	....	35.0	6.0	....	....	215.0	57.6	33.3	30.0	31.0	26.5	18.0	56.5	49.0	25.4	5.1	81.0	81.0	.05	....	1.26	3.77	5.03	36	Olaa
Lihue	27	100	70.4	K,2RC78,S72,12RM78	18x42(2),28x54(6),28x48(6)	191.2	176.3	2.7	.07	61.7	12	180	....	....	9.4	4.0	4.0	27	24.2	18.9	....	....	48.2	78.2	....	....	....	226.6V_1	37.6	39.1	56.0	36.0	25.3	21.5	81.3	57.5	20.1	....	97.4	70.8	.03	....	1.26	3.78	5.04	27	Lihue
Haw. Sug.	16	65	70.4	K,2RC72,S72,12RM78	20x42(2),28x54(6),28x54(6)	227.5	161.2	5.2	....	56.1	5	156	....	....	....	....	....	16	21.5	....	18.0	....	64.6d	91.4	....	....	....	203.2	35.4	48.5	51.9	41.2	23.4	23.1	75.3	64.3	26.4	....	92.3	92.3	.23	....	1.16	4.99	6.92	16	Haw. Sug.
Honolulu	13	60	70.4	K(2),2RC78,12RM78	28x48(6),28 11/16x60(9)	636.0	....	5.71	.781	66.71	9	180	....	....	25.0	11.7	....	13	23.3	....	11.7	....	50.0d	80.3F	....	149.3p	....	184.9	95.9	57.6	113.8s	60.0s	44.4	30.3	158.2	90.3	8.8SK	....	362.8	....	....	....	5.80c	4.80	10.60	13	Honolulu
Kekaha	25	65	50.0	K(2),2RC54,15RM60	16x32(2),28x54(9),24x54(6)	189.0	195.4	2.9	....	....	10	200	....	....	31.3	4.1	6.3	25	10.8	9.2	....	....	66.7d	65.8	3.8	89.9p	....	192.3	26.0	30.5	41.1	34.8	6.0	11.6	47.1	46.4	19.4	....	197.0	24.6	.04	....	1.93	3.87	5.80	25	Kekaha
Haw. Agr.	30	55	50.4	K,3RC60,12RM66	24x48(6),26x54(9)	407.7	....	4.7	.60	66.5	5½	110	5½	125	11.4	....	....	30	21.5	....	12.2	102.8	....	110.9	....	90.9p	....	327.3V_2	32.7	52.3	31.5	33.4	22.5	21.8	54.0	55.3	57.4	....	47.8	....	....	292.8	3.05	4.57	7.62	30	Haw. Agr.
Onomea	34	55	50.4	K,2RC60,S54,12RM66	22x42(5),26x54(9)	231.5	89.5	4.4	.72	33.7	6½	100	....	....	....	....	....	34	25.8	....	....	61.7	....	80.0	....	....	....	290.9V_2	22.9	27.9	30.0	29.1	13.0	16.7	43.0	45.8	18.5	11.0	....	130.9	.13	....	2.28	3.81	6.09	34	Onomea
Hilo	33	50	50.4	K,2RC66,12RM66	26x54(11),22x42(3)	394.9	....	....	....	....	7	143	....	....	....	....	....	33	23.7	....	....	78.0	....	120.8	....	80.0	208.4	....	33.6	50.4	35.6	35.4	25.0	20.0	60.6	55.4	18.0	....	160.1	....	....	179.5	2.51	5.02	7.53	33	Hilo
Makee	14	60	48.0	K,2RC72,S72,9RM72	16x36(2),28x60(9)	204.7	196.3	....	....	104.5	9¼	164	....	....	....	....	....	14	30.0	....	....	....	61.3	70.6	....	....	....	203.3V_1V_2	86.6	100.0	39.4	43.7	49.2	40.0	88.6	83.7	34.6	....	208.3	....	....	....	2.09	3.14	5.23	14	Makee
Honokaa	35	60	60.5	K(2),2RC66,15RM66	22x42(5),26x54(9),22x42(3)	108.7	254.0	3.8	.09	24.8	8	179	....	....	....	....	....	35	21.0	....	....	79.2	....	80.0	5.0	....	....	194.0	21.7	35.0	46.2	39.2	14.7	16.7	60.9	55.9	22.4	....	133.3	....	....	166.7	2.09	5.15	7.24	35	Honokaa
Wailuku	2	50	70.4	K,2RC72,12RM78	23x54(5),28 1/8x60(9)	241.3	152.4	3.7	....	56.6	10	150	....	....	10.0	7.6	0.5	2	25.3	....	....	88.5	....	88.2	....	80.5	....	244.3	54.0	42.8	35.0	29.0	28.0	28.0	63.0	57.0	28.7	....	256.0	....	....	....	1.68	6.28	7.96	2	Wailuku
McBryde	12	55	65.3	K,2RC72,S72,9RM84	24x48(5),28x48(6)	331.3	....	2.0h	....	47.5	10½	225	....	....	22.7	10.0	9.1	12	26.3	....	....	....	60.8d	119.6	....	67.4	....	218.8	58.9	59.9	32.3	34.5	28.6	30.9	60.9	65.4	97.2	....	129.4	114.6	.15	....	2.28	3.81	6.09	12	McBryde
Hakalau	7	35	41.7	2RC54,12RM9-60,3-66	20x54(11),18x48(3)	344.7	145.1	5.5	.27	48.6	5	325	....	....	....	....	....	7	19.8	15.9	....	98.9	....	120.0	....	85.7	....	286.5	47.3	59.7	32.2	36.0	19.2	21.3	51.4	57.3	39.6	....	277.4	....	....	159.3	2.39	5.98	8.37	7	Hakalau
Laupahoehoe	41	35	33.3	K,3RC60,9RM60	24x54(6),24x56(6)	282.1	217.7	3.4	.10	64.4	6½	150	....	....	2.3	....	....	41	20.3	....	....	60.6	....	100.0	....	....	....	283.2	42.9	54.3	60.0	52.1	24.7	31.4	84.7	83.5	78.4	....	200.0	....	....	....	2.39	7.11	9.50	41	Laupahoehoe
Kahuku‡	43	40	48.0	K,2RC80,S54,9RM72	14x36(2),28x48(9)	269.8	190.5	....	....	....	8	150	....	....	15.0	7.5	7.5	43	...	20.4	...	80.0	....	150.0	....	....	....	342.6	45.0	32.0	46.8	49.0	27.0	22.1	73.8	71.1	30.2	....	91.0	75.0	.18	....	2.09	4.58	6.67	43	Kahuku‡
Kolou	38	40	50.4	K,2RC60,12RM66	24x48(5),24x48(6)	....	311.8	4.5	.12	....	6	120	....	....	1.9	1.5	....	38	31.5	13.1	...	54.8	....	104.1	5.6	....	....	232.3V_1	36.7	45.9	29.0	27.5	22.5	25.0	51.5	52.5	21.6	....	63.8	103.5	.09	....	2.14	3.67	6.81	38	Kolou
Waiakea	3	30	33.3	K,3RC60,9RM60	22x42(3),26x54(9)	....	450.3	3.7	....	....	7	115	....	....	16.7	7.5	....	3	23.7	....	....	....	73.3d	133.3	....	....	....	330.7	37.1	48.9	76.3	50.7	28.6	24.0	104.9	74.7	73.1	....	280.0	....	....	....	2.79	4.19	6.98	3	Waiakea
Pepeekeo	19	30	33.3	2RC54,9RM60	26x54(1)	146.2	254.0	4.7	.61	55.3	7½	130	....	....	....	....	....	19	24.2	....	23.3	....	50.0	116.7	....	83.3	207.0	....	381.7	30.0	37.9	39.0	43.8	30.8	81.7	69.8	23.6	....	70.0	106.7	.17	....	2.79	5.58	8.37	19	Pepeekeo
Hamakua	15	30	41.7	K,2RC60,12RM60	22x42(5),26x54(9)	....	423.3	4.0	....	36.0	7	120	....	....	7.5	4.0	1.2	15	38.8	....	....	....	121.8F	....	....	....	....	329.0	41.0	49.5	44.6	45.0	11.0	14.2	55.6	59.2	36.9	....	....	133.3	.20	480.3	4.19	4.27	8.46	15	Hamakua
Paauhau	24	35	50.4	2RC60,12RM66	20x48(5),26x54(9)	103.1	235.9	4.8	....	25.0	5	110	....	....	....	....	....	24	...	28.3	....	83.4	....	121.1	....	....	....	241.2	26.5	22.3	37.9	38.5	14.6	11.7	52.5	50.2	18.9	8.9	....	....	....	717.7	2.39	3.59	5.98	24	Paauhau
Hutchinson	31	35	33.3	K,3RC60,9RM60	22x42(3),26x40(9)	282.0	145.1	5.4	.30	....	6	140	....	....	14.3	6.3	.9	31	23.7	16.6	19.4	63.2	....	121.1	....	....	....	357.1V_1V_2	34.2	79.9	38.9	34.3	27.3	22.9	66.2	57.2	47.4	....	228.6	....	....	....	2.39	4.19	6.58	31	Hutchinson
Kohala (Hawi)	26	35	33.8	K(2),2RC54,12RM54	22x42(3),24x48(9)	295.7	86.2	4.3	....	77.1	6	105	6	105	15.0	8.6	3.4	26	37.9	....	....	78.6	....	128.6	....	140.2	255.7	....	49.4	41.0	48.2	42.1	20.4	17.0	68.6	59.1	29.9	....	267.4	....	....	....	2.39	5.98	8.37	26	Kohala (Hawi)
Honomu	37	35	33.3	K,3RC60,9RM60	24x48(5),24x48(6)	88.9	228.6	2.2	....	68.5	7½	120	....	....	....	....	....	37	41.3	....	11.0	72.7	....	128.0	....	72.0	....	221.2	41.0	40.3	39.0	41.4	15.1	15.1	54.1	54.5	39.6	....	185.0	....	....	136.0	3.35	5.13	8.48	37	Honomu
Kohala	40	30	33.3	K(2),12RM60	22x48(6),24x48(6)	488.6	....	6.3	.10	36.2	6	138	....	....	3.1	....	....	40	26.7	....	....	69.9	....	136.8	....	....	248.4	....	39.0	75.2	38.9	32.7	20.7	23.5	59.6	56.2	47.7	....	....	216.7	.14	....	2.09	4.97	7.06	40	Kohala
Kaiwiki	32	30	33.3	K,2RC60,9RM60	16x36(2),24x54(9)	....	338.7	4.5	....	46.4	6	100	....	....	....	....	....	32	...	35.9	....	79.5	....	85.0	....	....	....	202.5V_1	17.6	45.0	30.0	19.7	7.7	8.7	37.7	28.4	55.3	....	....	....	....	605.3	1.83	1.83	3.66	32	Kaiwiki
Waimanalo	1	25	27.0	K,3RC54,9RM54	20x42(6),20x42(6)	313.5	....	5.2	.77	80.1	6½	140	....	....	15.0	....	....	1	38.9	....	....	79.6	....	140.8	....	....	....	329.0	30.0	67.8	48.0	48.0	24.0	24.0	72.0	72.0	66.3	21.0	336.0	....	....	....	2.35	5.03	8.38	1	Waimanalo
Kilauea	23	30	33.3	K,3RC60,9RM60	18x42(3),24x54(9)	201.1	169.3	6.0	....	78.7	6½	115	....	....	....	....	....	23	...	18.2	....	83.2	....	107.4	....	73.3	....	174.3	44.2	20.7	50.1	47.7	11.0	11.0	61.1	58.7	32.8	....	120.0	....	....	1,105.4	2.79	3.36	6.15	23	Kilauea
Waianae	9	30	33.3	K(2),3RC60,9RM60	24x42(9),20x42(3)	....	338.7	4.0	....	43.3	7	126	....	....	....	....	....	9	26.7	....	....	80.0	....	154.1	....	....	....	215.9V_1V_3	20.0	30.0	31.9	26.8	24.0	25.0	55.9	51.8	26.4	....	73.3	36.7	.16	....	2.09	2.09	4.18	9	Waianae
Kaeleku	47	30	33.3	K,2RC54,9RM60	14x36(2),26x54(9)	....	338.7	4.0	....	38.4	5	105	....	....	....	....	....	47	...	39.9	....	76.5	....	79.6	....	28.1	117.8	....	44.2	25.1	31.7	26.7	6.0	6.7	37.7	33.4	40.7	....	....	....	....	713.3	2.44	1.83	4.27	47	Kaeleku
Union Mill	11	20	25.0	K,3RC60,6RM60	18x42(3),24x48(6)	....	401.3	2.3	....	....	6	135	....	....	....	....	....	11	35.0	....	....	103.5	....	175.6	....	....	....	242.6V_1	75.4	32.5	72.6	48.0	37.7	25.5	110.3	73.5	55.0	....	....	216.0	.34	....	2.09	7.59	9.68	11	Union Mill
Niulii	39	20	20.3	K,9RM54	18x42(6),18x42(3)	....	254.0	4.7	....	27.4	4½	114	....	....	....	....	....	39	30.2	....	....	63.5	....	80.3	....	....	138.4	....	57.6	76.8	12.5	20.0	8.5	10.0	21.0	30.0	46.0	....	....	....	....	550.0	1.83	3.67	5.50	39	Niulii
Waimea	4	20	20.4	2RC42,12RM42	....	....	254.0	2.5	....	96.0	5	100	....	....	....	....	....	4	....	28.5	....	91.1	....	67.5	....	47.5	....	194.5	49.5	26.5	37.5	31.5	4.5	3.5	42.0	35.0	28.3	....	78.0	26.0	....	216.2	1.83	3.00	4.83	4	Waimea

* Two tandems.
‡ Does not include equipment for carbonation process.
b Boiler data from Bureau of Boiler Inspection.
h Hearth area.
† Does not include 3 oil fired boilers, 2523 sq. ft. H. S.
P Divided clarification.
d Dorr.
K Kopke centrifugal separators.
F Does not include 1,337 sq. ft. area used for refining operations.
p Vapor from pre-evaporator also used to boil massecuite.
V_1 Vapor from first cell used for heating juice.
V_2 Vapor from second cell used for heating juice.
V_3 Vapor from third cell used for heating juice.
S Includes one pan of 2,276 sq. ft. h.s. and 1,200 cu. ft. for refining operations.
SK Supplemented by 2 Shutte-Koerting condensers.
C Includes 146.6 sq. ft. screen area for refined sugar.

CANE MILL DATA, SEASON OF 1931

Factory	Factory No.	MILLING PLANT (Sizes in inches)	REVOLVING KNIVES: First Set: Number	First Set: Distance Apart Inches	First Set: Distance from Conveyor Inches	First Set: Revolutions per Minute	Second Set: Number	Second Set: Distance Apart Inches	Second Set: Distance from Conveyor Inches	Second Set: Revolutions per Minute	MILL OPENINGS: Crusher	1st Mill: Front	1st Mill: Back	2nd Mill: Front	2nd Mill: Back	3rd Mill: Front	3rd Mill: Back	4th Mill: Front	4th Mill: Back	5th Mill: Front	5th Mill: Back	Factory No.	SPEED OF ROLLERS—FEET PER MINUTE: Crusher	1st Mill	2nd Mill	3rd Mill	4th Mill	5th Mill	6th Mill	PRESSURE ON ROLLERS—TONS PER LINEAR FOOT: Crusher	1st Mill	2nd Mill	3rd Mill	4th Mill	5th Mill	6th Mill	Tons Cane per Hour	Ton-nage Fiber Ratio	Factory No.	Factory
H. C. & S. Co.	6	K(2),2RC34x78,S72,12RM34x78	28	9 3/4	24	1,200	56	5	16	1,200	1/16	3/16	1/16	3/16	0	1/8	0	1/8	0	....	....	6	30	25	24	30	24	....	....	29.2	67.4	61.5	70.8	79.7	....	....	56.19*	21.2	6	H. C. & S. Co.
" "	6	K(2),2RC34x78,S72,12RM34x78	28	9 3/4	24	1,200	48	5	16	1,200	1/16	3/16	1/16	3/16	0	3/16	0	3/16	0	....	....	6	30	25	24	31	24	....	....	29.2	67.4	61.5	70.8	79.7	....	....			6	" "
Oahu	20	K,2RC34x78,S72,12RM35x78	28	5 1/2	18	490	..	....	.....	....	1/8	5/8	0	5/8	0	1/2	0	1/2	0	....	....	20	37.2	25.6	17.6	19.8	21.2	....	....	39.4	76	73.5	76	71.1	....	....	69.03*	22.9	20	Oahu
"	20	K,2RC34x78,S72,12RM35x78	28	5 1/2	18	490	..	....	.....	....	1/8	5/8	0	5/8	0	1/2	0	1/2	0	....	....	20	37.2	25.6	17.6	20.2	20.7	....	....	40.9	72.3	63.5	65.1	65.7	....	....			20	"
Ewa	5	K(2),2RC33x78,18RM34x78	72	1	16	570	72	1	1/2	570	1/4	1	1/8	7/8	0	3/4	0	7/8	1/8	5/8	0†	5	21	20	21	24	23	26	30	38.5	69.2	69.2	69.2	49.2	67.7	70.8	80.77	19.9	5	Ewa
Waialua	17	K(2),2RC33x78,15RM34x78	76	1 1/2	16	580	76	1 1/2	2	580	1	3/8	1/16	3/8	1/16	3/8	0	3/8	0	3/8	0	17	46.2	32.4	28.1	29.0	31.3	26.4	...	46.2	76.9	76.9	80	80	83.1	...	107.24	31.2	17	Waialua
Maui Agr.	21	K(2),3RC34x66,12RM34x66	72	7/8	10	900	72	7/8	7/8	900	7/8x1/4	3/8	0	1/2	0	3/16	0	1/16	0	....	....	21	...	...	...	...	...	...	...	60	62	65	70	80	...	...	46.05*	24.0	21	Maui Agr.
" "	21	K(2),3RC34x66,12RM34x66	72	7/8	10	900	72	7/8	7/8	900	7/8x1/4	3/8	0	1/2	0	3/16	0	1/16	0	....	....	21	...	...	...	...	...	...	...	60	62	65	70	80	...	...			21	"
Pioneer	10	K,2RC35x78,S72,15RM34x72	27	2 1/2	16	690	..	....	.....	....	1/4	7/16	3/32	7/16	1/32	7/16	1/32	7/16	1/32	7/16	0	10	43	26.8	27.9	24.3	26.6	32	...	49.7	81	73.3	72	72	78.2	...	84.85	31.4	10	Pioneer
Olaa	36	K,2RC34x78,S72,12RM34x78	26	2 1/2	12	600	..	....	.....	....	1/4	3/4	1/8	11/16	1/8	5/16	0	1/4	0	....	....	36	49.1	33.2	25.6	29.9	35.1	...	...	35.4	63.8	49.2	63.8	63.8	...	...	86.23	30.8	36	Olaa
Lihue	27	K,2RC34x78,S72,12RM34x78	18	3 3/4	14	517	..	....	.....	....	1/16	1	0	5/8	0	1/2	0	1/4	0	....	....	27	55.6	31.7	31.7	31.3	36	...	...	36.9	66.6	67.8	67.1	82	...	...	84.92	30.6	27	Lihue
Haw. Sug.	16	K,2RC27x72,S72,12RM34x78	36	3	12	560	..	....	.....	....	1/4	3/8	0	5/16	0	1/4	0	3/16	0	....	....	16	32.5	20.2	23	21.5	22.5	...	...	41.7	77.9	77.9	77.9	80	...	...	65.33	23.8	16	Haw. Sug.
Honolulu	13	K(2),2RC34x78,12RM35x78	24	3	14	570	26	2 9/16	3	575	1 1/2	1/2	1	1/8	1/4	3/8	1/16	1/2	0	....	....	13	26.5	21.1	24.2	23.7	24.2	...	...	40.3	67.7	74.3	76	78.3	...	...	48.74	16.6	13	Honolulu
Kekaha	25	K,2RC24x54,15RM32x60	20	2 7/10	6	690	..	....	.....	....	1 1/2	1 1/8	3/8	1	1/4	7/8	3/16	3/4	1/8	5/8	1/16	25	25	20.2	22	23.2	23	23	...	...	67.2	68	75	76.4	78.4	...	57.76	28.5	25	Kekaha
Haw. Agr.	30	K,3RC32x60,12RM32x66	22	2 1/2	2	495	..	....	.....	....	5/8x1/2	1/4	1/4	11/16	1/16	1/2	1/16	3/8	0	....	....	30	23.8	22.2	22.5	25.1	27.3	...	...	71.5	70.2	73.3	73.3	73.6	...	...	51.31	24.1	30	Haw. Agr.
Onomea	34	K,2RC28x60,S54,12RM32x66	22	2 1/2	14	450	..	....	.....	....	1/4	3/4	1/16	5/8	0	3/8	0	1/4	0	....	....	34	31	22.4	22.3	22.3	22.5	...	...	15.4	73.1	76.4	76.4	79.3	...	...	56.06	26.7	34	Onomea
Hilo	33	K,2RC32x66,12RM32x66	24	2 3/8	1	400	..	....	.....	....	1/8	3/4	1/16	1/4	0	1/4	0	3/8	0	....	....	33	40.2	24.5	23.3	26.4	17.9	...	...	32.5	68.7	68.7	68.7	79.3	...	...	49.67	25.6	33	Hilo
Makee	14	K,2RC34x78,S72,9RM34x72	22	3	6	500	..	....	.....	....	0	5/8	0	5/16	0	1/4	0	....	....	....	....	14	52.6	19.3	22.6	25.5	...	...	...	41.7	72.8	74.7	76.7	...	...	...	55.72	29.0	14	Makee
Honokaa	35	K(2),2RC30x66,15RM32x66	16	4	14	400	16	4	4 1/2	500	1/2	9/16	1/16	1/2	1/32	3/8	0	3/16	0	3/16	0	35	33.2	23.8	20.9	25.4	28	24.5	...	36.4	69.9	56	56	69.9	77.3	...	49.81	24.7	35	Honokaa
Wailuku	2	K,2RC30x72,12RM34x78	26	2 9/16	3	575	..	....	.....	....	5/16	3/8	0	3/8	0	5/16	0	1/4	0	....	....	2	34.5	30.1	16.3	18.6	22.1	...	...	35.3	70	66.7	68.3	75	...	...	45.23	15.2	2	Wailuku
McBryde	12	K,2RC34x72,S72,9RM34x84	76	1 1/2	6 1/2	690	..	....	.....	....	3/8	1/2	0	7/16	0	13/32	0	....	....	....	....	12	33.5	19.5	19.5	20.5	...	...	...	41.7	67.9	70.7	73.1	...	...	...	51.10	20.6	12	McBryde
Hakalau	7	2RC24x54,12RM9-32x60,3-32x66	..	....	....	...	..	....	.....	....	1/4	3/4	0	1/4	0	1/8	0	1/4	0	....	....	7	30.5	21.6	24.3	26.7	16.1	...	...	...	64.4	64.4	67	69.1	...	...	35.61	20.2	7	Hakalau
Laupahoehoe	41	K,2RC30x60,9RM32x60	16	3 1/2	2	400	..	....	.....	....	1/2	9/16	0	1/4	0	1/4	0	....	....	....	....	41	30.5	21.8	17.4	19.3	...	...	...	45	75.2	75.2	75.2	...	...	...	30.88	22.5	41	Laupahoehoe
Kahuku	43	K,2RC30x60,S54,9RM34x72	10	6	24 1/2	420	..	....	.....	....	7/16	1/4	0	5/32	0	5/32	0	....	....	....	....	43	31.5	16.8	19.2	22.1	...	...	...	27	88.3	73.3	80	...	...	...	39.45	19.4	43	Kahuku
Koloa	38	K,2RC27x60,12RM32x66	12	4 1/2	9	300	..	....	.....	....	1/8	1/2	3/16	3/8	1/16	1/4	0	3/16	0	....	....	38	24.8	17.3	19	17.3	19	...	...	36	72.7	72.7	72.7	72.7	...	...	37.97	19.5	38	Koloa
Waiakea	3	K,2RC27x60,9RM32x60	38	5 1/2	4 1/2	385	..	....	.....	....	1/8	1/2	0	1/4	0	3/16	0	....	....	....	....	3	27	18.6	21	23.2	...	...	...	26	71	68	69.6	...	...	...	28.86	22.2	3	Waiakea
Pepeekeo	19	2RC24x54,9RM32x60	..	....	....	...	..	....	.....	....	1/8	3/4	0	3/16	0	1/8	0	....	....	....	....	19	31.4	21.7	23.7	26.1	...	...	...	...	77	77	77	...	...	...	30.15	23.3	19	Pepeekeo
Hamakua	15	K,2RC30x60,12RM32x60	32	4	3	400	..	....	.....	....	3/8	1/2	1/32	9/16	1/32	5/16	0	3/16	0	....	....	15	27.2	17.2	17.6	19.3	21.8	...	...	...	74	70.4	72	77.6	...	...	31.39	19.2	15	Hamakua
Paauhau	24	2RC26x60,12RM32x66	..	....	....	...	..	....	.....	....	0	3/8	0	1/4	0	3/16	0	1/8	0	....	....	24	23.6	14.5	17	18.9	20.8	...	...	...	73.6	71.3	63.7	69.6	...	...	28.19	14.4	24	Paauhau
Hutchinson	31	K,3RC33x60,9RM32x60	22	2 1/2	3	495	..	....	.....	....	5/8x0	1/2	0	1/4	0	1/8	0	....	....	....	....	31	24.6	17.2	19.2	21.2	...	...	...	84	76.4	76.4	71	...	...	...	30.41	23.1	31	Hutchinson
Kohala (Hawi)	26	K(2),2RC28x54,12RM30x54	12	2 1/2	16	600	18	2	0	600	3/8	1/4	1/8	3/16	0	1/8	0	1/8	0	....	....	26	38.2	27.3	29.9	23	23	...	...	33.3	66.7	88.9	77.8	83.3	...	...	36.05	27.0	26	Kohala (Hawi)
Honomu	37	3RC33x60,9RM32x60	..	....	....	...	..	....	.....	....	3/4x1/8	3/8	0	3/16	0	3/16	0	....	....	....	....	37	22.2	18.7	21.4	23.8	...	...	...	71.3	64.8	66.7	66.7	...	...	...	26.80	19.2	37	Honomu
Kohala	40	K(2),12RM3-30x60,9-32x60	18	3 1/2	18	375	26	2 1/2	1 1/2	400	.....	5/8	1/8	1/4	0	1/8	0	1/16	0	....	....	40	....	22	19	25	28	...	...	...	...	75	64	75	...	...	27.70	18.0	40	Kohala
Kaiwiki	32	K,2RC24x60,9RM32x60	18	12	3	350	..	....	.....	....	1/2	1/2	1/16	1/4	0	3/16	0	....	....	....	....	32	23.3	17.5	19.9	22	...	...	...	...	...	...	...	...	...	...	28.03	21.2	32	Kaiwiki
Waimanalo	1	K,3RC32x54,9RM30x54	28	1 7/8	3 1/2	550	..	....	.....	....	3/8x0	3/8	0	3/16	0	1/8	0	....	....	....	....	1	20.4	18.4	18.6	19	...	...	...	79.6	79.6	79.6	79.6	...	...	...	25.58	25.3	1	Waimanalo
Kilauea	23	K,3RC32x60,9RM32x60	22	2 1/2	2 1/2	370	..	....	.....	....	3/8x1/8	1/4	0	3/16	0	1/8	0	....	....	....	....	23	20.5	18.3	24.8	19.2	...	...	...	62	68	62	62	...	...	...	28.20	23.4	23	Kilauea
Waianae	9	K(2),12RM9-30x60,3-32x60	44	2 1/2	10	490	44	2 1/2	1 3/4	490	.....	1	1/4	1/2	0	1/2	0	3/8	0	....	....	9	....	16.9	16.9	16.9	17.6	...	...	...	70	70	70	70	...	...	28.41	19.4	9	Waianae
Kaeleku	47	K,2RC24x54,9RM32x60	9	6	8	250	..	....	.....	....	1/4	5/8	1/16	1/4	0	1/8	0	1/8	0	....	....	47	19.8	16.6	18	20.4	...	...	...	...	67.6	67.6	67.6	...	...	...	29.56	26.3	47	Kaeleku
Union Mill	11	K,9RM30x60	15	3 3/4	12	450	..	....	.....	....	.....	3/4	1/16	1/4	0	3/16	0	....	....	....	....	11	....	16.5	18.9	21.2	...	...	...	...	69.6	62.2	66	...	...	...	21.53	24.1	11	Union Mill
Niulii	39	K,9RM30x54	20	5	3	500	..	....	.....	....	.....	7/8	1/16	1/4	1/32	3/16	0	....	....	....	....	39	....	27.6	22.5	23.1	...	...	...	...	48.0	52.7	52.7	...	...	...	19.32	26.9	39	Niulii
Waimea	4	2RC24x42,12RM26x42	..	....	....	...	..	....	.....	....	0	1/2	0	3/8	0	1/4	0	1/8	0	....	....	4	18.9	13.6	13.6	14	17	...	...	...	57.1	57.1	48	48	...	...	17.11	20.5	4	Waimea
Olowalu	18	K,3RC28x48,9RM26x48	16	3	2 1/2	610	..	....	.....	....	3/8x0	3/8	0	1/4	0	3/16	0	....	....	....	....	18	22.5	20.9	20.1	20.1	...	...	...	57.5	57.5	65	65	...	...	...	15.46	19.5	18	Olowalu

* Tons Cane per one tandem.

† 6th Mill openings ½x0.